SLAC-PUB-548

CONCLUDING REMARKS: WHERE DO WE STAND?

Matthew Sands

Stanford Linear Accelerator Center
Stanford, California

From the Proceedings of Symposium on Electron Ring Accelerators
Lawrence Radiation Laboratory, Berkeley, California, 1968
(UCRL Report 18103, pp. 127-132)

CONCLUDING REMARKS: WHERE DO WE STAND?

Matthew Sands

Stanford Linear Accelerator Center
Stanford, California

February 13, 1968

I would like to limit my comments primarily to what we can now say about the feasibility of an Electron Ring Accelerator for high-energy protons. When considering such a radical new concept as the ERA we should ask two basic questions:

(I) Can such a machine work? (That is, does it not violate any fundamental principle? Is there a choice of the design parameters which will permit the realization of a working accelerator?)

(II) If such a machine can be built, would we want to build one? (That is, is it "economical," particularly in the sense that it would compete favorably with alternative methods of producing high-energy beams?)

With respect to the first question, we have heard several sub-questions posed and discussed.

(1) Can one make a stable compressed electron ring with the desired properties? The answer seems to be that there is no fundamental reason why a useful stable ring could not be made; although we can not yet say for sure what restrictions there may be on the various parameters (e.g., ring dimensions and density) which are critical to the overall performance of the accelerator.

(2) Can a stable ring be loaded with a significant number of protons and ejected into an accelerating column? Again, it seems quite likely that techniques can be developed for passing from a ring which is

held together by externally applied restoring forces to a ring which is self-focussed, and that such a ring can be squirted out of the initial formation region.

(3) Will a loaded ring remain stable under the large accelerations desired? Again, it seems possible that a suitable choice of parameters can be made for which the ring will retain its identity while undergoing large accelerations.

For each of the regimes considered there are known pitfalls, and we cannot say with certainty that there exist parameters which will guarantee certainty of operation. It now seems likely that the pitfalls can be avoided, but more work is needed--both theoretical and experimental--to increase our confidence that all of the problems can reasonably be solved.

With respect to the second major question, we have heard a preliminary cost estimate which indicated that, for one tentative set of parameters, a 70 GeV accelerator might be constructed for a cost of about $20 million. On the same basis, a conventional alternating gradient synchrotron of the same energy might cost perhaps $40 million to $50 million. The cost of the ERA would appear to be favorable. Indeed, the primary attractiveness of the ERA idea is that it may offer a cheaper avenue to accelerators of very high energy. It is, of course, too early to take seriously any cost estimate of an ERA, but it is perhaps not too early to emphasize the importance of searching for parameters and techniques which will minimize the costs of an eventual practical accelerator.

One of the most striking aspects of the cost estimate we heard was the large fraction of the cost (about 50%) represented by the cost of the equipment which supplies RF power for the accelerating system. If the unit costs were to remain the same, the costs of the RF power source would be even more dominant for accelerators with a final energy greater than 70 GeV.

It seems worthwhile, therefore, to take a look at the reason for the large RF costs and to search for ways to reduce them.

The preliminary studies seem to indicate that the costs associated with the construction of the RF acceleration system will be determined primarily by the impulsive energy required for each acceleration cycle--and will be much less dependent on the pulse rate, or average power. Assuming that this tentative conclusion is correct, it is instructive to ask what are the basic determinants of the RF costs.

The cost of providing the required RF power can always be written in terms of the significant parameters of the accelerator as follows:

$$C_{RF} = C_o \eta N_e \frac{\gamma_o m}{M} E_p \quad ; \qquad (1)$$

E_p and M are the final energy and rest mass of the proton, and $\gamma_o m$ is the electron energy in the frame of the ring. So $\gamma_o m E_p$ is the final energy of the electrons; and N_e times that quantity is the energy delivered to the electron ring during the whole acceleration cycle. If we then characterize the RF equipment by C_o, the cost per unit of RF energy generated, and by η, the ratio of the RF energy supplied to the accelerating structure to that which is received by the electrons (so that $1/\eta$ is the "efficiency" of the RF system), the product shown gives the total cost of equipment for generating the RF energy. (It is assumed that the total energy given to the protons carried in the ring is much less than that given to the electrons.)

The usefulness of the formula given here depends, of course, on the magnitude of the RF power costs in relation to other costs. If C_{RF} were to dominate all other costs, the formula gives some indication of the significance of the values of parameters such as N_e or γ_o. On the other hand, if the RF power costs can be made negligible in comparison with other costs, the formula is of no particular significance--it would offer no guide to the selection of parameters.

We can try to get some feeling for the possible significance of the RF costs by taking some numbers we have heard during this conference--each of which has been suggested as a reasonable possibility:

$$E_p = 60 \text{ GeV}$$

$$N_e = 10^{14}$$

$$\gamma_o = 100$$

$$\eta = 30$$

$$C_o = \$100/\text{joule}$$

(It may be worth remarking that the maximum RF coupling efficiency at SLAC corresponds to $\eta \approx 15$, whereas at SLAC the RF costs were several times greater than the $100/joule shown.) If one uses the parameters above in Eq. (1), one gets that $C_{RF} \approx \$150M$. Such a cost would surely dominate the other costs! It would also become a primary consideration in arriving at a choice of the parameters (N_e, γ_o, etc.) of the ring.

The values taken above for N_e and γ_o were, of course, the extremes of what has been suggested. The values referred to most often have been $N_e = 10^{13}$ and $\gamma_o = 50$. Suppose we could design an RF system with a 10% coupling efficiency ($\eta = 10$), which does not seem impossible *a priori*, and could reduce the costs of the RF generators to $30 per joule (which is still well above the $1 per joule usually estimated for simple capacitor-discharge systems. With these new parameters our formula would give $C_{RF} = \$0.7$ million. Such a cost would certainly not be a dominant one. We would, in fact, be in the region where the formula is not relevant since even for the RF systems, costs not associated with energy delivered would probably dominate.

I should emphasize that neither of the two numbers derived above should be interpreted as a "cost estimate." They do, however, lead to the following conclusions:

(1) The economic feasibility of a high-energy electron ring accelerator may depend critically on the costs associated with the accelerating system. There is a need for fundamental studies -- and inventions -- of structures and systems which will have a high efficiency for coupling electromagnetic energy to an electron ring at low cost. It may be that conventional RF structures and sources are not the most suitable. It is certainly not yet obvious that an oscillating field is the most sensible way to couple energy into a single blob of charge. An impulsive transient field would certainly do as well, and may be more practical or efficient. We have, in fact heard at this symposium some specific suggestions for systems which would generate transient fields which would couple energy into a traveling electron ring. They should receive serious theoretical and experimental study.

(2) The choice of parameters required to achieve stable electron rings may -- if they lead to large values of γ_o and N_e -- have a strong impact on the overall cost of a high-energy accelerator. There is, therefore, some need for considering such factors while pursuing studies and experimentation on the generation of stable rings.

I have digressed somewhat from my assignment to make some "concluding remarks" -- which should, I suppose, say something about the future. What can we conclude today about the future of the Electron-Ring Accelerator? At the moment, my personal conclusions are these:

(a) The ERA concept offers the exciting possibility of achieving beams of very high energy protons at reduced cost.

(b) This conference has led to a deeper understanding of the many new problems faced in an ERA device -- and has disclosed <u>no fundamental impediment</u>.

(c) There are good reasons to hope that a high-energy ERA will be feasible. We should, therefore, push hard on theoretical and experimental investigations on the generation and acceleration of stable electron rings.

With luck we should be able to have soon -- perhaps in a year or two -- a definite and realistic picture of the future potential of the Electron Ring Accelerator.