

FURTHER ACCELERATORS IN THE UNITED KINGDOM

A complete list of all high energy nuclear physics machines which could be considered is easily compiled. It is useful to categorise under three headings -

- I Can be built with existing knowledge.
- II Require development.
- III Require basic investigation.

Machines which exist or are being constructed in the U.K. are not included.

I Can be built with existing knowledge

- 1. Electron/Positron linear accelerator.
- 2. Electron Synchrotron.
- 3. Proton Linear Accelerator up to 150 MeV.
- 4. Proton Synchrotron up to 30 GeV.

II Require development

- 5. Cyclotron - Spiral Ridge - fixed frequency - up to $\frac{m_0 c^2}{2}$ i.e. 400-450 MeV.
- 6. Cyclotron - Spiral Ridge - frequency modulated - above 400 MeV.
- 7. Proton Linear Accelerator above 150 MeV.
- 8. Proton Synchrotron - Alternating Gradient - energy greater than 30 GeV.
- 9. Proton Synchrotron - Alternating Gradient - high repetition rate - medium energy.

III Require basic investigation

- 10. Cyclotron - Spiral Ridge - fixed frequency - up to $m_0 c^2$ i.e. 800-900 MeV.
- 11. Proton Synchrotron - F.F.A.G. - Spiral Ridge.
- 12. Proton Synchrotron - F.F.A.G. - Radial Sector.
- 13. Proton Synchrotron - F.F.A.G. - Radial Sector - Two way colliding beam.
- 14. Storage Rings. ?

To the accelerator designers at the Rutherford Laboratory there is little difficulty in ascribing each of these machines to its particular category. Our reasons can be given quite briefly.

- I. 1. For an electron linear accelerator with a modest duty cycle and an energy of a few GeV the principles are well known and proven. Industry can usefully participate right from the beginning and can be entrusted with the majority of manufacture on a mass production basis. For the acceleration of positrons some variants are required but these too will in the main draw on existing knowledge. For a higher duty cycle component development is required but this is of an industrial nature. For an

energy in the region 10 to 40 GeV there are some problems such as phasing of a very long machine which require a certain amount of scientific attention, and there should be more emphasis on industrial development particularly from the point of view of economy and reliability.

2. The MIT-Harvard machine and the Hamburg machine represent virtually the ultimate in energy from electron synchrotrons. Beyond 7 GeV the radiation loss becomes an overbearing economic disadvantage.
3. The extension of the Proton Linear Accelerator to an energy in the region of 150 MeV is best achieved with a continuation of the Alvarez type of resonant cavity. The problems are technological ones.
4. The remarkable success of the C.E.R.N. P.S. must indicate that intelligent copying might achieve the same result.

II.

5. At about 150 MeV the Alvarez zero mode resonator for the 2π mode acceleration of protons falls markedly in overall efficiency. Up to this point the acceptance of an increasing transit-time loss across the gaps can be used to maintain reasonable R.F. efficiency, but beyond it a radical change to a π mode resonant system is essential. The basic problems of coupling together a multitude of π mode cavities have been solved by a particular method. This method requires development towards engineering feasibility, and other schemes might well be tried. At a still higher energy various travelling wave schemes become possible and ultimately a conventional corrugated waveguide with quadrupoles incorporated in the dividing walls could be considered. The various frequency changes need careful consideration from the point of view of particle dynamics. Up to 50 MeV we have used 200 Mc/s so as to have a reasonable aperture for the initial acceleration. At 50 MeV the frequency can be increased to 400 Mc/s and it is likely that a further increase could be made in the region of 600-1,000 MeV. There are commercially available valves in the U.S. for 400 Mc/s which are close to our ideal for the next step beyond 50 MeV. The π -meson region is therefore within sight particularly if British equivalents can be assured. A further increase in frequency and a change to travelling wave acceleration implies a considerable programme of valve development.
6. It has been shown theoretically that a fixed frequency (spiral ridge) cyclotron has a high probability of giving cyclotron like currents up to an energy of about 400-450 MeV. [As a kinetic energy equal to a half the proton rest energy is approached there must be a half integral resonance in the radial motion. A method of delaying this resonance has been proposed, but such improbable variations of geometry and parameters are required as to make the idea repulsive.] Theoretical and experimental development would be required before the basic parameters could be fixed.
7. The radial resonances in a spiral ridge cyclotron can be avoided by applying frequency modulation such as to allow a lower field gradient consistent with a variation of radial Q value between 1 and $1\frac{1}{2}$. There would still be considerable economy in weight of magnet and in a much smaller range of frequency modulation as compared with a normal synchrocyclotron. The probability of success is high but the duty cycle of such a machine would be comparable with a synchrocyclotron. It is possible, with higher dee voltage and other measures, that the current would be greater than one expects from a synchrocyclotron but it would be much less than the fixed frequency

machine. Theoretical and experimental development would again be required as in the fixed frequency case, with the addition of a considerable problem of a somewhat technological nature in developing a suitable R.F. system with high R.F. voltage and fast recycling.

8. An alternating gradient synchrotron for an energy substantially greater than 30 GeV would require very careful assessment making full use of the C.E.R.N. experience. A direct scale with total energy would be expensive and probably not very sensible. The development should follow the lines of a theoretical investigation in conjunction with an analysis of tolerances, engineering realisation and economics.
 9. The success of the C.E.R.N. P.S. gives encouragement to the exponents of a high repetition rate A.G. Synchrotron. The magnet would be resonated with a condenser bank, and a reasonable energy would be in the region of 15 GeV. The repetition rate to be aimed at for a significant increase in mean proton current would be say 25-50 c/s. Much theoretical work can be done to relate aperture to betatron oscillations, synchrotron oscillations, tolerances and so on. Serious development is required to determine whether the necessary energy gain per turn with appropriate R.F. tracking and phase lock can be achieved.
- III.
10. The effect of the first half integral resonance in the radial motion of a fixed frequency cyclotron is something of an unknown quantity. There are some who believe that the loss of particles will not be too serious and that acceleration up to the region of the first integral resonance (800-900 MeV) should be possible. There are others who find this difficult to accept and who would rather use frequency modulation. Basic investigation is certainly required.
 11. A Spiral Ridge Synchrotron is the "cheaper" form of F.F.A.G. The particle dynamics in a machine without radial-cut straight-sections are well understood and much attention has been given to beam stacking. The introduction of radial-cut straight-sections gives non-scaling dynamics and it is extremely difficult to see how the R.F. systems can be inserted in the very short straights which are permissible. Some attention could also be paid to the desirability (or necessity) of using R.F. phase lock.
 12. The radial-sector F.F.A.G. Synchrotron has relatively simple dynamics. There are no non-scaling troubles with straight sections. The circumference factor however is of the order of 5 to 6 as compared with 2 or less for a spiral ridge machine. There are common R.F. problems but the most serious reason for saying that basic investigation is required is that the cost of designs so far considered is quite prohibitive.
 13. The radial-sector two-way synchrotron does not differ greatly from the simple radial-sector machine. (In fact one would probably always use a two-way magnet design.)
 14. Storage rings for electrons of energy about 600 MeV are being made at Stanford. Radiation damping of betatron oscillations gives a means of beam stacking. For protons no such natural mechanism exists. A combination of a single turn inflector and R.F. beam stacking system has been proposed.

These machines could be categorised in other ways, by cost, effort required and so on. The accelerator itself is not however the whole problem. Much money and effort is involved in opening up a new site, providing laboratories, offices, service buildings and services, buildings and shielding for the accelerator, experimental areas, nuclear physics apparatus and a multitude of other things.

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