PROTON LINEAR ACCELERATORS

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(presented by P. D. Dunn)

1. Introduction

A design study for a 600 Mev machine with a mean current of 1 microampere has been completed. Developments in efficiency of the synchrocyclotron extraction system at Liverpool and the possibility of fixed frequency cyclotron operation to several hundreds of Mev make such a project unattractive. Construction will not proceed beyond 50 Mev.

2. Particle dynamics

Theoretical studies showed that stable phase motion could be maintained by careful control of amplitude and phase throughout the R.F. system and that ample damping was achieved at 50 Mev for a reduction of wavelength from $1\frac{1}{2}$ metres to 75 cm. With the apertures considered an electro-magnetic quadrupole system was feasible from 10 Mev upwards. The permissible tolerances for "misalignments" were tight but possible. "Coasting" without acceleration was found to be quite feasible over considerable energy ranges.

3. Accelerating structures

Structures and detailed systems can now be specified for the whole range of velocities from .03c to 1.0c. Each system is derived as a logical link on the basis of :—

R.F. efficiency.

Tolerances on frequency, temperature and temperature gradient.

Mechanical tolerances and engineering considerations.

Provision for focusing (A.G. magnets in drift-tubes).

Spark breakdown.

(*a*) *Alvarez 2 π mode*

Working designs have been specified up to 50 Mev with $1\frac{1}{2}$ metres wavelength and to 150 Mev (0.5c) with 75 cm. Other structure such as helices and interdigital devices were also studied for the low velocity range.

The Alvarez structure for low velocities has remarkably high efficiency and inherent coupling, but at 150 Mev the efficiency is falling so rapidly that a change of structure can no longer be delayed.

The subsequent structure reverts to individual cylindrical E_{010} cavities with posts, with suitable coupling into longer units each fed by a single 400 Mc/s amplifier. The degree of coupling involves a compromise between R.F. efficiency and frequency and temperature tolerances; tight coupling gives wider tolerances but, the increased stored energy in the lossy coupling mechanism reduces the overall efficiency.

(*b*) *π – mode*

Over the range .4c to .9c (approximately 90 Mev to well beyond 600 Mev) the efficiency of uncoupled cavities is highest in π mode. Very tight coupling is required for tolerance reasons and even to overcome the variations of amplitude and phase which are associated with power

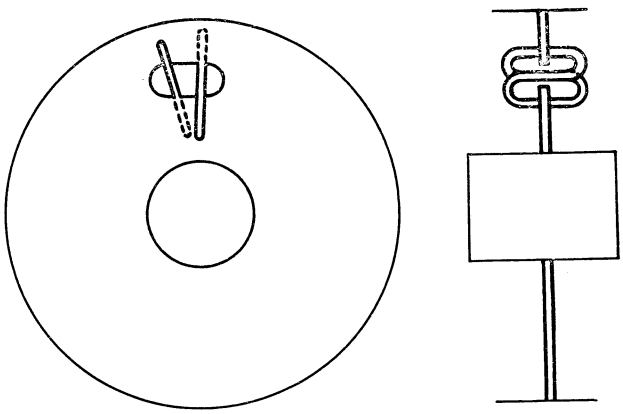

Fig. 1.

flux down a system which is "resonant" at the end of its pass band.

Various shapes and distributions of holes in the dividing walls did not give sufficient coupling without seriously reducing the overall efficiency. However, coupling systems which have a self-resonant frequency near to that of the cavity can give tighter coupling without seriously increasing the R.F. losses. If desired such a system can become a " confluent band-pass" filter.

A system of near-resonant loops, connected through holes in the cavity dividing walls, were found to give very satisfactory results (fig. 1). Such loops have been used to couple 10 full size 400 Mc/s cavities to form a tank 2.16 m. long. The following results were obtained from low power measurements with the tank end-fed (representing a centre fed tank of 4.3 m.) :—

	Uncoupled	Coupled
Shunt impedance η_0	28.5 M Ω /m.	22.8 M Ω /m.
Q	22,300	17,800

The measured η_0 together with transit time and stable phase angle factors correspond to a total power consumption of about 90 MW for 150-600 Mev with a mean accelerating rate of 2.3 Mev/m.

It was found possible to set up the tank to give a field uniformity better than 1% without great difficulty, by successive addition of cavities and each time tuning the the last cavity added and making a small adjustment to the previous cavity. A temperature difference of 17 °C between the ends of the tank caused a variation in field of 10%. The inherent phase error was within the limits of experimental accuracy ($1^3/_4°$) equal to the theoretical value of $1^1/_2°$.

(*c*) *Travelling wave*

For travelling wave operation again with E_{010} cavities forming a section length of about 6 metres, a feedback ratio of the order of three is essential. Such a feedback system has been fully investigated at 10 cm. wavelength with enough success to demonstrate feasibility at 75 cm. There are no serious coupling problems. The range from 0.4 c to 1.0 c can be covered with an efficiency comparable to that of the π mode, initially with a structure giving $3\,\pi/2$ phase shift as seen by the particles, but actually carrying a $\pi/2$ mode wave travelling in the opposite direction, and at higher energies with a conventional $\pi/2$ mode structure.

4. Conclusion

There appears to be no major technical obstruction to acceleration of protons to any energy.