PROTON LINEAR ACCELERATOR STRUCTURES FOR INTERMEDIATE VELOCITIES

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The dominant feature of linear accelerators is RF power, and the efficiency of its use is determined by the accelerator structure. Up to now linear accelerators have been built with either of two structures:

a). Alvarez drift-tube-loaded circular TM01 mode waveguide operating in the 2π standing wave mode which is the low-frequency cutoff of the lowest propagation band. Such structures are efficient for low particle velocities and have been used for proton and heavy-ion linacs.

b). Iris loaded circular TM01 mode waveguide operating with a running wave or in the π standing wave mode (the high-frequency cutoff of the lowest propagation band). These structures are reasonably efficient for velocities approaching c and have been used for electrons.

In recent years several groups have proposed multi-100 MeV proton linacs. Aside from their complexity the principal design problem is the relative inefficiency of known structures at the intermediate velocities which comprise major fractions of such accelerators. We have solution to this difficulty and will attempt only to outline the problem. Its solution requires a new invention.

Walkinshaw et al. at Harwell first pointed out the falling shunt resistance of Alvarez drift-tube linacs with increasing particle velocity, and further work has verified this behavior as a general result. Fig. 1 shows the results of several calculations for such structures. We see that for β above one-half the best practical drift-tube structures are at least four times as inefficient as the infinite TM010 mode waveguide (a standard of comparison having no significance except for a well designed drift-tube structure at low β).

The qualitative reason for this deterioration is simple. An Alvarez drift tube is a dipole, and the current on its surface must reach the gap face in order to produce an accelerating field. With high β the unit cells are long and most of the current leaves the drift tube surface as $\dot{D}$ before it reaches the gap. Thus over most of the drift tube large currents circulate which contribute nothing to the axial gap field. Variations of the gap-to-cell-length ratio or the drift-tube diameter and shape

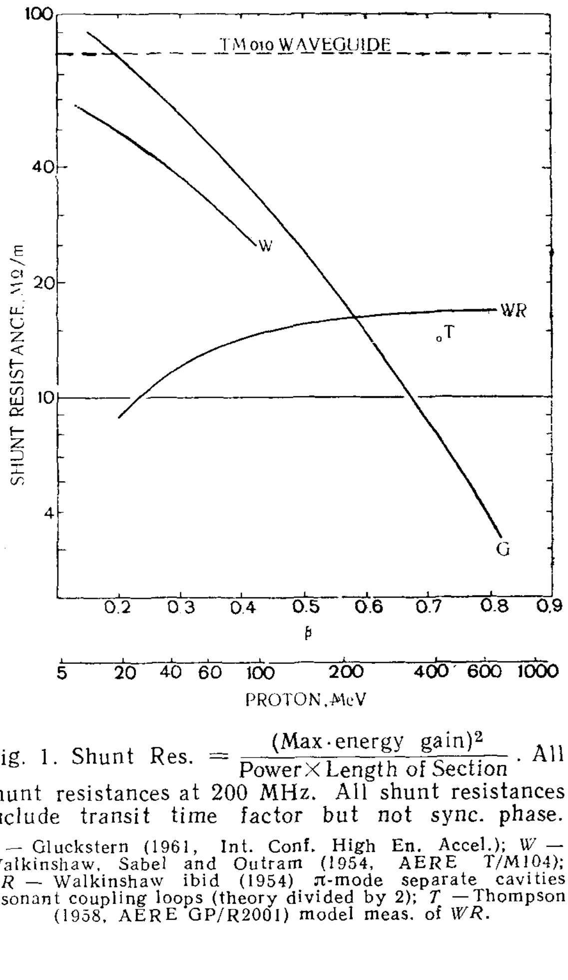

Fig. 1. Shunt Res. $= \dfrac{(\text{Max}\cdot\text{energy gain})^2}{\text{Power}\times\text{Length of Section}}$. All shunt resistances at 200 MHz. All shunt resistances include transit time factor but not sync. phase.

G — Gluckstern (1961, Int. Conf. High En. Accel.); *W* — Walkinshaw, Sabel and Outram (1954, AERE T/M104); *WR* — Walkinshaw ibid (1954) π-mode separate cavities resonant coupling loops (theory divided by 2); *T* —Thompson (1958, AERE GP/R2001) model meas. of *WR*.

make minor changes in shunt resistance but cannot overcome its deterioration with β.

At sufficiently high velocities axial post-loaded TM010 resonators are more efficient because of their shorter drift tubes. One trades drift-tube losses for back-wall losses with a net gain. In 1954—58 considerable work

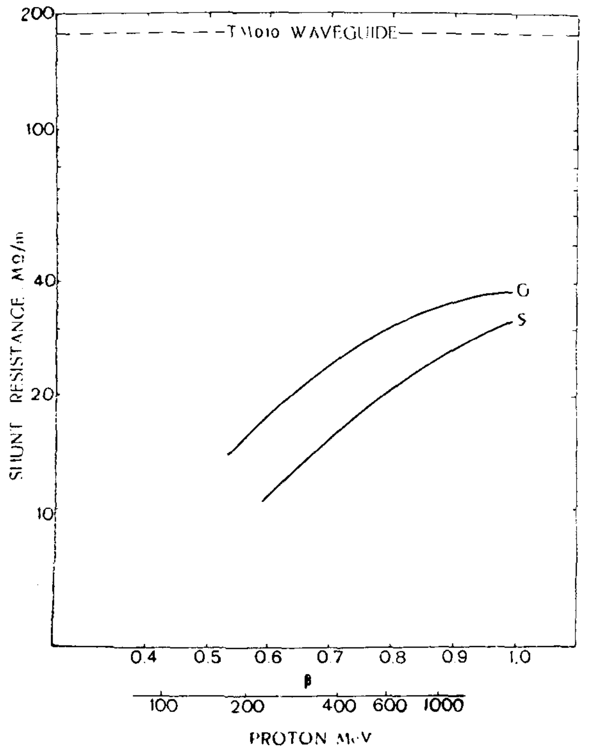

Fig. 2. All shunt resistances at 1000 MHz. All shunt resistances include transit time factor but not sync. phase.

G — Gluckstern (1961, Int. Conf. High Energy Accel. and 1962—63, unpublished) π-mode standing wave, shaped irises; *S* — Stanford U. $2\pi/3$-mode running wave, plane irises.

was done at Harwell on coupled structures consisting of many such cavities operating in the π standing wave mode. Fig. 1 shows some of their results. The inefficiency and complexity of the coupling schemes have kept this from being a generally accepted answer.

Another structure, still under study, is the π mode cross-bar, a variation of the transverse rod-loaded waveguide. This structure is basically a set of side-by-side coaxial half-wave cavities with their common walls removed and resonating with π phase shift between cells. The rods are fitted with drift tubes and secondary drift tubes on cross-bars are placed between them in order to improve the transit-time factor.

At high velocities iris-loaded waveguides are accepted as suitably efficient and, although by comparison with low β drift tubes they are rather poor, their simplicity overcomes efficiency arguments. As β decreases toward one-half the progressive decrease in shunt resistance becomes objectionable, and although design details can improve matters they cannot change the trend. Fig. 2 shows two such curves and the Harwell cross-bar. The results are given at 1000 MHz which is a suitable frequency for a proton linac of iris-waveguide geometry. The reason for the deterioration is again qualitatively simple. At low β the loading is increased and larger iris currents are required for the same axial field (an iris is essentially a ring monopole fed from adjacent cells). At any β the iris losses are dominant.

Our final word is an approach toward structure invention. We argue that an efficient structure should produce its loading by perturbing an efficient waveguide field as little as possible and that the circulating current paths should be as short as possible. The best structures have these features. Very impressive results for this structure are presented at this conference by A. Carne. His shunt resistances lie well above those for the Alvarez structures of Fig 1. We believe Carne' s results to be overly optimistic.