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The Yale University 800 MEV proton accelerator and possible accelerating R. F. structures.

The Yale University proposal is directed to a proton accelerator with output energy of approximately 800 MEV; output particle current 0.1 to 1 ma of protons (average current) and a high duty cycle, i.e., of the order of 5 percent.

A good beam quality is certainly desirable although demands would not go further than 0.1 percent for $\Delta E/E$. Regarding phase spread, one would accept whatever comes out. Beam quality would, of course, be of concern if one would like to go to some sort of beam stacking device.

It should be understood, not withstanding the work devoted to a linear accelerator design, that other accelerating structures are being considered such as a FFAG type and c.w. Cyclotron type accelerator. At present, ideas are not optimized and no thoughts are being given to hardware.

A key parameter to the design of any linear accelerator is R_{sh}, the shunt resistance, defined as

$$\frac{R_{sh}}{\ell} = \frac{E^2}{(P/\ell)}$$

where R_{sh}/ℓ is the shunt resistance per unit length (ohms/m.), E is the axial field (V/m.) and (P/ℓ) is the power dissipated per unit length (watts/m.). The cost and complexity of the whole accelerator design will vary quite closely with the value of $(R_{sh})^{-1}$. Other parameters such as value of operating frequency and focusing are considered secondary problems. As long as one kind of accelerating structure has no definite advantage over the next one in connection with beam quality, etc., the guiding factor should be R_{sh}.

It is useful here to review briefly some well known accelerating structures.

a. Alvarez type drift tube linac (2π mode).

In this case R_{sh} is approximately equal to R_{sh} for an unloaded waveguide with TM_{010} mode ($56.5 \sqrt{f}$ Ω/cm). Studies by the group at Harwell indicated the following. At low β values $R_{sh} \cong R_{sh}$ for TM_{010} mode; as β increases R_{sh} deteriorates; for β values of 0.5 R_{sh} is bad. Consequently, it can be said that long drift tubes are inefficient, its losses will overtake other considerations. However, in the region of β values of 0.1 to 0.5 further studies are desirable.

b. π-mode independent cavities:

The Harwell group has studied this type of structure, which seems to be good for values of $\beta > 0.5$, maybe up to 0.8. This seems to be a desirable design in connection with R_{sh} , however, coupling is a difficult problem in this design and the best the Harwell group could do was to use S-shaped coupling loops with consequent difficulties with high dissipation, resonances, engineering, etc. It has been done at low power in experimental models and was rather inefficient in terms of loop losses. Hole coupling was tried, but was rather unsuccessful.

c. Other basic type of accelerators.

Iris loaded types.

c 1) $\pi/2$ traveling wave as used in the Stanford electron accelerator. At $\beta = 1$, the R_{sh} is about 1/6 of R_{sh} for the TM_{010} mode. This will be worse for $\beta < 1$, and certainly be bad for β values below 0.6. This type of structure is being considered by R. Gluckstern. Considering the particular case of the iris loaded Stanford machine R_{sh} could go down by as much as a factor of 15 for $\beta = 0.5$ as compared with $\beta = 1$.

c 2) Iris loaded π-mode standing wave (M.I.T. design). R_{sh} for a well designed π-mode standing wave structure should be within 10% of a traveling $\pi/2$-mode structure (R.S.I. Feb. 1955). This, however, is open to argumentation and apparently contested by various persons.

c 3) In the design of a proton accelerator following the $\pi/2$-mode traveling wave technique of the Stanford group, several differences should be mentioned.

1. The electron accelerator uses a 1 μsec. pulse and has a filling time of 1 μsec., so that by the time the reflected wave arrives, the amplifier will be off. In long pulse accelerators, this will not be so and the reflected wave somehow must be controlled. This may not be serious and only leads to phase shifts. However, a study of this point seems necessary.

2. In electron accelerators $\beta = 1$ and a taper in E field, which accompanies the traveling wave, is of no importance. However, at $\beta < 1$, the taper in E field must be controlled. In a standing wave machine, the E field is automatically flat and depends only on tuning.

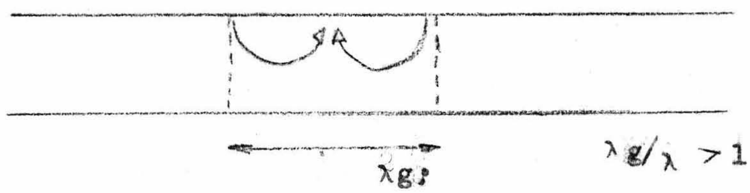
3. With high electron current machines, one has had beam blow-up problems which should be given due consideration in a proton accelerator.

Yale University has studied several types of standing wave cavities.

a. Shaped drift tube structures for 2 π mode and π mode (separate cavities). To be elaborated by R. Gluckstern.

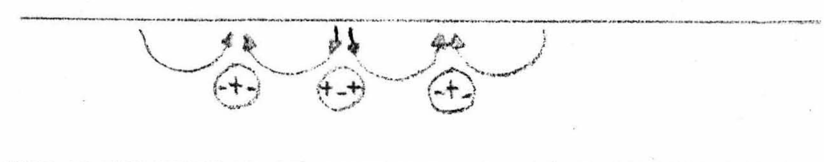
b. Quadrupole drift tube type structure for a long π-mode accelerator.

Consider a TM_{01n} mode in a round pipe as follows:



Is it possible to start with this TM_{01n} mode and load it to produce an accelerator?

It has been done with iris loaded guides. Apparently it can also be done with drift tubes, as sketched below.



Drift tubes of this type behave like oscillating electric quadrupoles, just as Alvarez drift tubes behave like oscillating electric dipoles. The problem is to obtain sufficient loading with such drift tubes, i.e. $\frac{\lambda_g}{\lambda} = \beta < 1$. Perturbation calculations show that loading is in the right direction and model measurements have produced β values as low as 1.

The possibility also exists of combining this with weak iris structures, in order to lower β. R. Gluckstern will elaborate on calculations related to the pure structure and the above mentioned combination. The impression at present is that R_{sh} will be favorable.

c. Shaped irises. (π mode and $\pi/_2$ mode).

Calculations will be outlined by R. Gluckstern.