THE YALE DRIFT TUBE LINAC

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The present version of the Yale linac drift tube table consists of six cavities. The injection energy is 0.75 MeV and the ejection energy from the sixth cavity is approximately 190 MeV. Table I gives a summary.

The first tank is relatively short being about 5.5 meters. The conventional square Alvarez drift tubes were employed because: 1) space available inside the drift tube for the installation of a quadrupole magnet is critical; 2) little improvement can be seen by using shaped drift tubes in this low-loss end of the drift tube linac. This design was chosen for several reasons: (1) the need for a relatively low gap gradient of 7MV/m, which is as high as seems safe, in order to avoid sparking problems, but only until β is sufficiently large to justify a higher gradient; (2) a point is reached where values of the shunt impedance can be increased considerably by going from square to shaped drift tubes. Thus, the point $\beta = 0.14$ (~ 9 MeV) seems to satisfy both of these conditions and the first tank was terminated there.

Gluckstern's shaped drift tubes(1) have been obtained at $\beta = 0.10$ (~ 5 MeV) and values of the shunt impedance some 10-15% higher than those of the square drift tubes

TABLE I

Tank No.	1	2	3	4	5	6
β_{in}	0.0400	.1399	.3147	.4117	.4756	.5206
W_{in} (MeV)	0.75	9.31	50.22	91.30	128.91	160.63
ΔW (MeV)	8.56	40.91	41.08	37.61	31.72	29.48
W_{out} (MeV)	9.31	50.22	91.30	128.91	160.63	190.11
β_{out}	0.1399	.3147	.4117	.4765	.5206	.5555
Tank Dia. (m)	0.948	.960	.900	.870	.855	.846
Tank Length (m)	5.55	26.59	26.15	24.65	21.67	22.59
Accumulated Length	5.55	32.14	58.29	82.94	104.61	127.20
D.T. Dia. (cm)	17.6	18.0 & 15.0	12.3-15.5	15.7-18.0	18.2-19.9	20.2-21.7
D.T. Length (cm)	4.7-13.9	17.3-32.4	35.2-39.4	40.9-43.2	44.0-45.4	46.0-47.0
D.T. Bore Dia. (cm)	1.5 & 2.0	2.0 & 2.5	3.0	3.5	4.0	4.5
Gap Length (cm)	1.5 - 7.0	3.8-14.4	12.1-22.0	20.9-28.0	27.5-32.4	32.1-36.1
P (theor.) (MW)	.34	1.26	1.89	2.38	2.46	2.45
P (total) (MW)	.65	2.58	3.47	4.08	4.08	4.02
Accumulated Power	.65	3.23	6.70	10.78	14.86	18.88
E_{max} (MV/m)	7	12	13	13	13	12
No. of D.T.s	42	77	48	37	29	28
Accumulated D.T.s	42	119	167	204	233	261
Average R (MΩ/m)s	70	75.4-52.1	53.1-35.4	35.0-26.4	26.2-21.5	21.4-18.2

have been calculated. However, these drift tubes are characterized by relatively small values of g/L, the gap-to-cell-length ratio. Consequently, the first tank has been based on the design of the heavy ion accelerator poststripper cavity and various parameters have been taken from model measurements for that machine. A constant drift tube diameter has been used and the length of a cell is calculated as $L_n = \beta_n \lambda$, where β_n is representative of the particle velocity entering the cell. The energy gain for the cell is then

$$\Delta W_n = E_g \, g_n \, T_{on} \cos\varphi_s$$

where T_{on}, the transit time factor for the axial particle, is

$$T_{on} = \frac{\sin(\pi g_n / L_n)}{(\pi g_n / L_n) \; I_o(2\pi a / L_n)}$$

and a is the bore radius. In step-by-step fashion the β_{N+1} at the next cell is calculated from the new energy

$$W_{N+1} = W_N + \Delta W_N$$

To reduce power losses, Gluckstern's shaped drift tubes were used in tanks #2-6 (9-190 MeV). Here, all parameters were obtained after optimized drift tubes (in the sense of maximum R_s) had been found at discrete values of β and interpolation formulas set up. The tank radius for a given cavity was chosen from a curve which represented the optimized tank radius as a function of β. A reasonable value of E_g (MV/m), the maximum field gradient for a tank is specified. As in the first tank, the calculation is then carried cell-by-cell with necessary parameters being obtained from optimized curves. Thus, the energy gain in a given cell is:

$$\Delta W_n = E_g \left(\frac{1}{R_N}\right) L_N \, T_{\ell N} \, T_r \cos\varphi_s$$

The initial β_n for a cell is assumed to be the effective value of β for the cell and the quantities

R = the ratio of E_{max}/E_{av}

T_ℓ = the longitudinal transit time factor

are interpolated from the optimized curves. The radial transit time factor is

$$T_r = I_o(2\pi a/L_n)^{-1}$$

The power requirement for the cell is

$$P = \frac{R_s^{-1}}{L_N} \left[E_g T_\ell L_n \left(\frac{1}{R_N}\right) \right]^2$$

where R_s is the shunt impedance for the cell and as calculated by Gluckstern, contains the longitudinal transit time factor.

In Table I the P(theoretical) is the sum of the cell power requirements throughout a tank. This does not include drift tube stem or end-wall losses. The P(theoretical) has been increased by 40% to allow for this. Thus, the P(total) represents these losses plus the power which is transferred to the beam,

$$P(\text{total}) = 1.4P(\text{theoretical}) - I\Delta W$$

The lengths of tanks #2-6 were picked in an attempt to avoid the difficulty of flattening a resonator which is too many wavelengths long. An effort was made to keep the individual tank lengths to approximately 20 wavelengths or less.

The first half of tank #2 has been designed using Gluckstern's double charge drift tubes. It will be recalled that the Yale drift tube program yields a shaped drift tube after fields have been generated by an axial dipole charge. A field node is found on the radial axis of the drift tube and the shape is initiated at this node and integrated through the cell such that the shape is everywhere perpendicular to the electric field. The configuration is seen in Fig. 1 along with a sketched electric field pattern. It was found that, if one wanted to optimize these single charge drift tubes (for high R_s) in the region $\beta = 0.14$ to $\beta = 0.22$, relatively small values of g/L (g/L ~ 0.08 @ $\beta = 0.14$; g/L ~ 0.13 @ $\beta = 0.22$) were obtained along with high values of R, the ratio of maximum-to-average field gradient. Placing multiple charges on

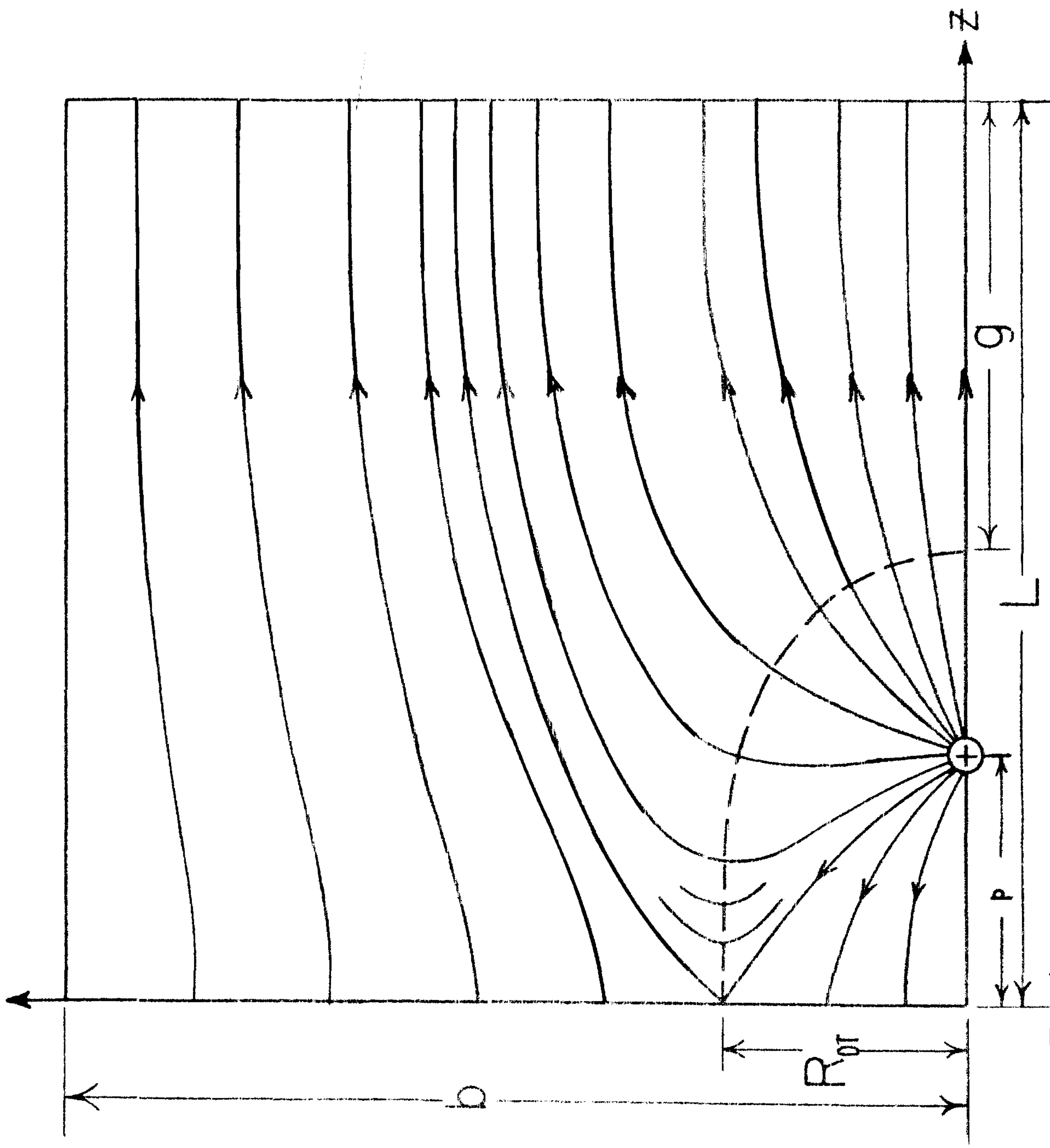


FIG.1- HALF CELL FOR DIPOLE DRIVEN CAVITY

the axis tended to reduce the losses but elongated the drift tube and further decreased g/L.

A solution was found by moving the charges off the axis and near the radial center of the drift tubes. Various combinations of charges were tried in this manner. In general, they tend to increase the losses somewhat but it was found that, while increasing the losses several percent, g/L could be increased by as much as 40%. The drift tube seen in Fig. 2 is such a structure. It might be noted here that the peak electric field on the drift tubes moves from a position at the tip of the drift tube in the 'single charge' case, radially up the drift tube in the case of these 'two-charge' configurations.

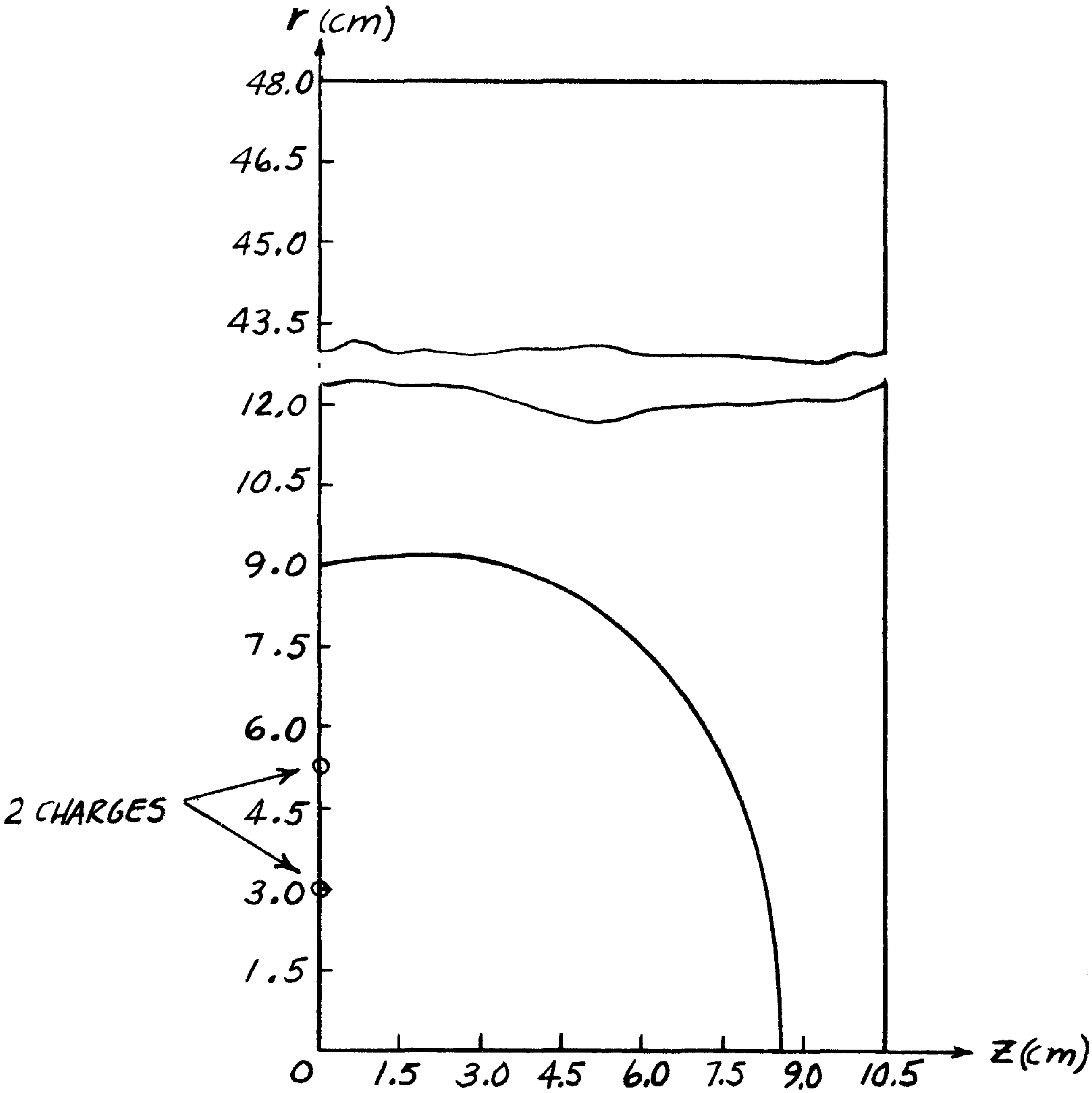
CARNE: What about the bore hole and its contribution to the transit time factor?

VITALE: We have not included bore holes in calculating the actual drift tube shapes. We have included a radial transit time factor in our drift tube table calculations. The transit time factor that we use is actually T_ℓ, the longitudinal transit time factor, times the radial transit time factor which takes into account the size of the bore hole. We've included the bore radius, a, in the factor $I_o\ (\frac{2\pi a}{L})$. I might mention that, as we go to the double charge drift tube, where the charges are off the axis, from the single charge on-axis drift tube, the position of E_{PK} in some cases, starts to rise. I have cases where the positions of E_{PK} are quite high on the drift tube. E_{PK} is the maximum electric field on the drift tube.

FIG. 2

DOUBLE CHARGE (OFF AXIS) DRIFT TUBE

$\beta = 0.14$, 200 Mcps



$T_\ell = 0.9451$ $g/L = 0.1814$

$R_s = 70$ $R\ (E_{max}/E_{av}) = 5.951$

CARNE: Certainly, in low energy cases, the drift tubes are going to have a very sharp radius of curvature near the bore hole and this is going to make E_{PK} critical. If you have a limiting value of E_{PK} that you must not go above and if you then put a bore hole in the drift tube your E_{PK} may go beyond that limit.

VITALE: I think this is not necessarily true. According to a MURA result, E_{PK}, for two identical geometries -- one with and one without a hole -- are roughly the same.

OHNUMA: In connection with this point, one thing we can do with our code, in some cases, is to adjust the configuration of charges so that our shaped drift tubes have bore holes.

VITALE: I have some cases where the drift tube shape was re-entrant enough to produce a bore hole. As far as our code was concerned, these cases are considered to be failures because if the shape hits anything but the longitudinal axis we call it a failure. It has possibilities, however.

CARNE (to WHEELER): How much does this thing cost in comparison with a conventional square drift tube? How much money can be saved allowing for the increased cost of manufacture?

WHEELER: We don't have detailed information on that point. It is certainly true that the shapes are going to be somewhat more expensive to fabricate than the simple drift tube. However, if you are making a number of them, you have the possibility of automatic programmed machinery to do the machine work. These shapes are cylindrically symmetrical so that they would be relatively easy to produce. I don't think it's going to make a big difference but it has to be studied.

SWENSON: I'd like to comment on the effect of holes in the drift tube on the E field. Since June we have made about 100 runs on our MURA program, most of which included holes for the beam. There may be in these data the answers to the questions pertaining to the effect of holes on the E fields. There are some cases where the calculated E fields are incorrect (as in the case of a square-cornered drift tube) but they were evaluated for all of the geometries we considered. If we concentrate on the calculations of the cases where there is a hole in the drift tube, where the geometry is a useful geometry, and where the contour in the median plane of the drift tube is a smooth contour, I think one can believe the E field calculations to a few percent.

YOUNG: I would like to make one comment about the runs that have been made with 3 or 4 cm holes, especially for drift tubes in the 150-200 MeV region. When you look at the cost curves for that geometry they are shifted upwards and the cost is increased a little bit. The reason this happens is that the peak fields have been increased a little.

Reference

(1) R. L. Gluckstern, Shaped Drift Tubes and Irises For Linear Accelerators, 1961 International Conference on High Energy Accelerators.