POST-COUPLER AND STEM CURRENT MEASUREMENTS FOR HIGH CURRENT CW DRIFT-TUBE LINACS

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Summary

Post-coupler characteristics have been measured on a model Alvarez tank for drift-tube-to-outer tank diameter ratios from 0.10 to 0.25. A maximum ratio beyond which field stabilization is not possible and a minimum ratio where stabilization is difficult have been determined. Field stabilization has been studied using two to twenty-one post couplers in a 22 cell tank. A sensitive dependence of the drift-tube stem currents near the tank end walls on the end cell geometry has been found.

Introduction

High-current, 100% duty cycle (cw) drift-tube linacs are under development at the Chalk River Nuclear Laboratories (CRNL) as part of the accelerator breeder program[1]. The high rf power dissipated in the cavity walls of such structures can result in large shifts of the resonant frequency as power levels are changed. Mechanical tuners are required in each accelerating structure to compensate for these shifts and to maintain an operating frequency that is common to all powered tanks. Post-couplers can be used to stabilize the on-axis electric fields against longitudinal field tilts produced by the mechanical tuners[2]. Field stabilization measurements with post-couplers have been carried out at CRNL on a 22 cell aluminum Alvarez tank model. A previous paper[3] described experiments using a post-coupler for each or for every second drift-tube that stabilized either a flat on-axis electric field distribution or a field distribution shaped for variable output energy. These measurements have been extended to investigate field stabilization as a function of drift-tube-to-tank diameter. In addition an investigation of various post-coupler geometries has shown that stabilization of the model tank was possible with as few as three post-couplers.

Overheating of the bellows connecting the drift-tube stem to the outer tank wall has been observed on a 3 MeV Alvarez tank operated in the cw mode at CRNL[4]; indeed, heating of stem joints has been a problem affecting drift-tube linacs since MTA[5]. Measurements on a 6 cell model show that the stem currents, which are most severe near the tank ends, are very sensitive to the geometry of the end cells.

Post-Coupler Measurements

Field stabilization with post-couplers is achieved when the stop band between the post-coupler mode dispersion curve and the TM_{01N}-like mode dispersion curve is closed[2]. Identifying the numerous post modes, which can be very closely spaced, is difficult for a cavity with many post-couplers. A new technique has been developed to find the region where fine tuning by the standard tilt measuring procedure can be used. After the on-axis gap fields are adjusted to the design tilt a bead pull without post-couplers is taken. Fields in gaps 2, 3 and 4 are averaged to determine a normalizing factor. The normalized field in gap i with no post-couplers is denoted $P_{i,n}$. A bead pull then is taken with post-coupler-to-drift-tube spacing of x, with the normalized $P_{i,x}$ denoting the corresponding ith gap field. A distortion parameter, D_x, is defined for each spacing by

$$D_x = \sum_i |P_{i,x} - P_{i,n}|$$

Figure 1 shows a plot of D_x as a function of the spacing, x, for a typical series of measurements. The distortion parameter D_x is relatively small when post-coupler mode frequencies are above the accelerating mode (large spacing). Severe distortion occurs as the band of post modes overlaps the accelerating mode. Finally, when the band of post modes is below the accelerating mode frequency, D_x again is small. The larger D_x values for small gaps as compared to that for large gaps is due mainly to errors in alignment of the post-couplers on the drift-tube centres. Once the distortion parameter curve is taken, fine tuning of the post-coupler lengths by the end-plate or tuner shift technique[2,3] is used.

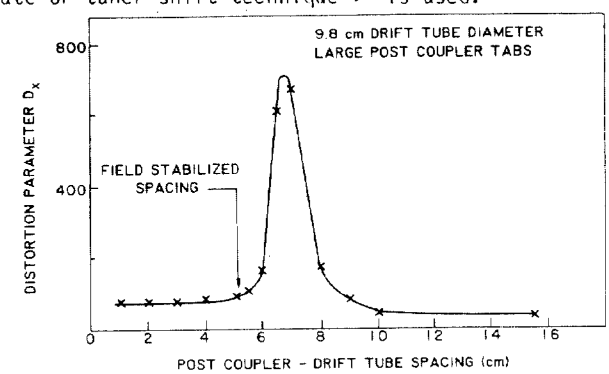

Fig. 1. Distortion parameter, D_x, as a function of post-coupler-to-drift-tube spacing.

The incorporation of permanent magnet quadrupoles to replace electromagnets in Alvarez tank drift-tubes allows a significant decrease in drift-tube diameter with a possible 20-30% improvement in tank shunt impedance. Problems have been encountered[6], however, with post-coupler stabilization of the accelerating field on the New England Nuclear 45 MeV linac that employs small diameter drift-tubes. The problem appears to be associated with a drift-tube diameter that is too small. Field stabilization as a function of drift-tube diameter has been investigated on the 22 cell model. The 0.508 m diameter tank is 1.02 m long and is a 0.72 times scale model of our operating 3 MeV proton drift-tube linac[4]. Four sets of drift-tubes with diameters of 57 mm, 76 mm, 98 mm and 125 mm were used. The drift-tube spacing and lengths were kept identical in all four geometries. Changing only the drift-tube diameter in a graded beta tank results in a non-uniform frequency change for the tank cells; SUPERFISH calculations showed that the difference in end cell frequencies is less than 1% - an effect that was considered negligible in the interpretation of the results of these experiments. Details of the post-coupler geometry and stabilizing technique have been previously published[3].

The results of the stabilization measurements as a function of drift-tube size are shown in Fig. 2. Ten post-couplers were used on the 21 drift-tubes. The

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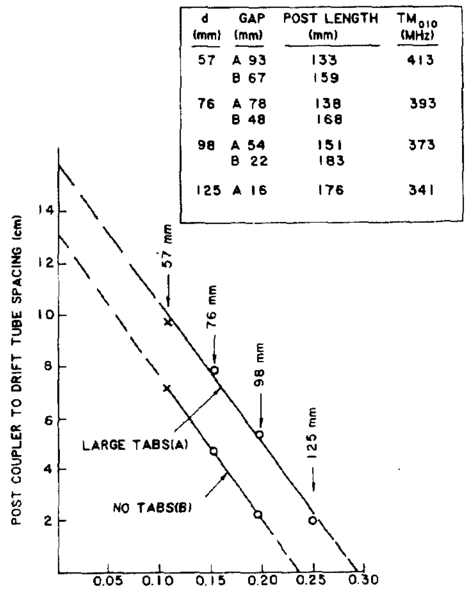

Fig. 2. Stabilized post-coupler-to-drift-tube spacing as a function of the ratio of drift-tube diameter (d) to the tank diameter (T).

post-coupler diameter, 19 mm, was chosen to be the same as that of the drift-tube stem. The large tabs were ∿ 5.7 times the area of the post-coupler ends[3]. For the 76 mm, 98 mm and 125 mm diameter cases a tilt shift of less than 1%/MHz was attained. (Tilt shift[1,3] is defined as the change in end cell field tilt as a function of cavity frequency shift. Without post-couplers the tilt shift on the model tank was 55%/MHz.) Field stabilization could not be achieved for the 57 mm drift-tubes. The spacing shown for this size on Fig. 2 was obtained only from the D_x curves.

The data of Fig. 2 show that as the drift-tube diameter, d, increases (T is the tank diameter) the TM_{010}-like mode frequency decreases and the length of post-couplers required for stabilization increases. Eventually a drift-tube diameter is reached that requires post-couplers longer than space restrictions allow. This situation occurs for the 125 mm diameter drift-tube and only by using very large end tabs was stabilization possible. No obvious reason for stabilization problems as d/T decreases can be seen from the data. The dispersion curves for large versus small drift tubes were measured and do show some differences

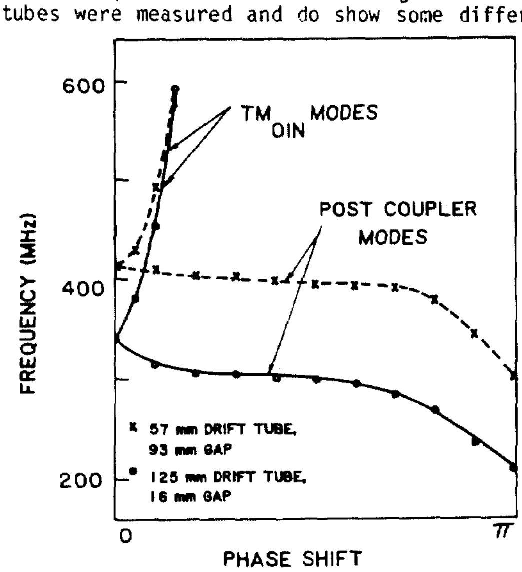

Fig. 3. Dispersion curves for 57 mm and 125 mm diameter drift-tubes.

as shown in Fig. 3 for the 57 mm diameter drift-tubes where stabilization was not achieved and for the 125 mm diameter drift-tubes where stabilization was possible. Frequency separation between the individual post modes and between the post modes and the accelerating mode decreased as the drift-tube diameter decreased. The flatter post mode spectrum, together with the low quality factor (Q ∿ 2300) for the aluminum cavity led to a situation for the 57 mm diameter case where interference between the upper post-coupler mode and the TM_{010}-like mode occurred at the correct gap spacing and field stabilization was not possible. Several different post-coupler configurations and sizes were used in an attempt to change the slope of the dispersion curve for the post modes but no solution was found. Increasing the tank and post-coupler Q will reduce this mode overlap problem but with a long tank and many post modes increased mode overlap problems would be expected.

A closer spacing of the TM_{01N}-like modes in the upper curve is evident. This mode spacing is strongly influenced by cavity length. (For a 1.05 m diameter cavity the lowest two modes are separated by 2.1 MHz for a 5 m long tank, but only by ∿ 70 kHz for the 27.6 m long New England Nuclear linac tank[6].) The 1.02 m long test cavity was reduced to 0.49 m by removing the 10 longest drift-tubes and repositioning the end plate at an appropriate position. Field stabilization with five post-couplers on the remaining eleven 57 mm drift-tubes was then achieved. Two factors are involved in this result - one factor is the reduced tank length with the associated change in the mode curve and the other is the reduction in number and hence the larger frequency spacing between modes of the lower post band.

The problem of identifying post-coupler modes can be reduced by decreasing the number of post-couplers and therefore the number of post modes. Previous measurements[3] showed that field stabilization could be attained on the 22 cell tank with either 21 or 10 post-couplers. The number of post-couplers has been further reduced and the same degree of field stabilization has been demonstrated with as few as three post-couplers in the model tank. The three post-couplers were located at approximately the 1/4, 1/2 and 3/4 tank points with the central post on the opposite side from the other two. In this geometry the post lengths necessary for stabilization decreased by ∿ 10 mm (from 170 mm for 21 posts to 160 mm with 3 posts). Attempts at field stabilization with only two post-couplers at a number of different locations along the tank were unsuccessful, although a reduction in tilt shift by a factor of two could be achieved.

The rf characteristics of the three post-coupler system have been investigated in some detail. Figure 4 shows frequencies of the three post-couplers both with and without drift-tubes in the cavity. The post mode frequencies without drift-tubes were ∿ 10 MHz higher than those measured for the same post lengths with the drift-tubes in place. The small shift showed that the post modes were not strongly affected by the presence of the drift-tubes except at small gaps. For post-coupler lengths less than 160 mm in Fig. 4, interactions between the various cavity modes and the post modes occurred and a deviation from the linear behaviour of frequency as a function of post-coupler length was observed. Measurements with small post-couplers (down to 3 mm diameter) both with or without end tabs produced similar curves to those of Fig. 4 and suggested one more method of determining the correct post-coupler-to-drift-tube spacing. Post-coupler frequencies could be adjusted to be located just below the anticipated TM_{010}-like mode frequency before installing the drift-tubes. Only

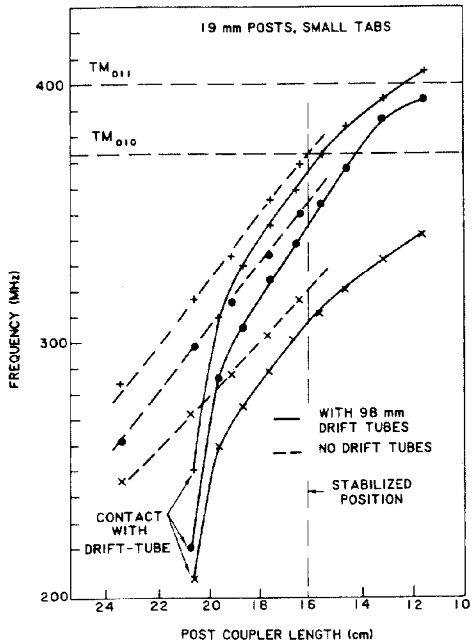

Fig. 4. Frequencies of the three post-coupler modes as a function of post length both with and without drift-tubes in the tank.

minor length adjustments would then be necessary when the drift-tubes were installed.

Stem Current Measurements

Severe rf heating of the bellows joining drift-tube stems to the outer tank wall under cw operation was previously investigated[4]. It was found that for the end cells, where the problem was most severe, changing the position of the tank end plate could reduce the heating by several orders of magnitude. Measurements on a 6 cell 0.40 m diameter by 0.50 m long model Alvarez tank have determined the relation between stem location on the drift-tube and stem current. The drift-tubes on the aluminum model were suspended from a top plate for easy removal and adjustment. Stems are normally mounted on the drift-tube centre line for mechanical ease. Since cell lengths increase along the tank, this mounting technique places the stem downstream some distance, X, from the cell boundary. On the model a series of mounting screw holes were tapped both on the centre line and offset from the centre line by 1, 2, 4, 8 or 16 times X. Choosing one set of mounting holes allowed the stems to be shifted relative to the drift-tube centre line while maintaining the cell geometry on-axis. For the model, X ranged from 0.51 to 0.58 mm.

Drift-tube stems were electrically insulated from the tank top plate and were connected via coaxial cables to power meters. The stem powers at a fixed tank power level were measured for the five drift-tubes as a function of the stem displacement. Figure 5 shows the results of the measurements for the first and last stems in the cavity. Stem power changed by a factor of > 1000 for 2-3 mm shifts in stem position for these two cells. The corresponding curves for the intermediate stems (not shown) were very similar in shape. The minima, however, all occurred with the intermediate stems within ± 0.3 mm of the drift-tube centre line.

The minimum power position for both end drift-tube stems was shifted from the geometric centre and towards the closest tank end. While for the first cell this shift was towards the cell boundary, for the last cell it was further away from the boundary. Currents associated with the lack of cell symmetry appeared to be the main contribution to these stem currents. One source of asymmetry in end cells is the drift-tube stem itself. Hemi-cylinders of the same radius as the drift-tube stems were added to each end plate (i.e., half-stems) to improve the symmetry in the end cells. The measurements of stem power versus displacement with this geometry are shown by solid curves in Fig. 5. The minimum stem power position coincides with the geometric drift-tube centre within the uncertainty of the measurement.

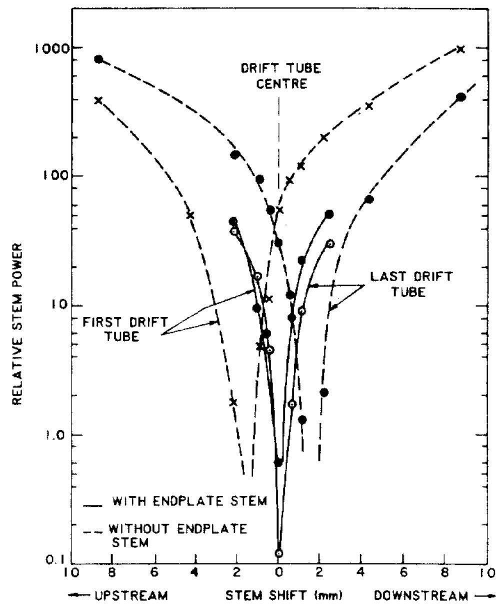

Fig. 5. End cell drift-tube stem power as a function of stem displacement from geometric drift-tube centre.

An alternative solution to using half-stems on the end plates to reduce stem current was also found. If the lengths of the half drift-tubes are reduced a curve similar to that shown in Fig. 5 can be obtained. The reduction in half drift-tube length (cell length maintained constant) required to minimize the stem currents corresponds to ~ 1.75 mm on the model tank. This change in the end cell geometry, however, results in a significant frequency shift (~ 2%) for these end cells and shifts the overall tank frequency. Calculated frequency shifts for the half drift-tube reduction are 10-20 times those measured for the perturbation from the half-stem. The addition of the half-stem to the tank end walls clearly provides the easier solution.

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