POST COUPLER STUDIES FOR ALVAREZ TANKS

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Summary

Field distributions of drift tube linac (DTL) with post couplers were measured in three models. They have three different ratios of drift-tube-to-wall spacing to one-quarter wave-length ($\lambda/4$). As the ratio becomes large, the limited range of post coupler length makes difficult to stabilize the field. But the ratios of post coupler length to $\lambda/4$ at stabilization were almost same in each model. The equivalent circuit model of DTL with post couplers were compared with measurements.

For another stabilization idea, strip line was installed in the tank and the field stabilization was observed.

Introduction

To get higher shunt impedance for higher accelerating efficiency, small drift tube diameter and/or large tank inner diameter are desirable in DTL. The recent developments of strong permanent Q-magnets enable to make drift tubes very small. The TM_{010} mode, accelerating mode of DTL, is susceptible to perturbation particularly in long tank, so the on-axis electric fields are easily distorted. Post couplers have been used to stabilize the accelerating field distribution. For the higher shunt impedance, the drift-tube-to-wall spacing increases more than $\lambda/4$, and it becomes more difficult to stabilize the field with post couplers.[1]

Three models with post couplers were examined for different drift tube diameters. The differences of field distributions and changes of excited mode frequencies were investigated.

Field Distribution

Three models had different ratios of drift-tube-to-wall spacing to $\lambda/4$, 1.0, 1.11 and 1.33. Parameters of each model are shown in Table 1. Every model had a post coupler opposite every other drift tube, and post couplers alternated side to side.

Field stabilizations with post couplers are measured as follows. A change of the half drift tube length on an end plate causes a frequency shift Δf from the original cavity resonant frequency f_0. One then adjusts the opposite half drift tube length to cause an opposite frequency shift $-\Delta f$, restoring the cavity frequency f_0. The standard bead-pull technique determines the on-axis electric field. As distortion parameter, Dx, which indicates the effectiveness of field stabilization, is defined as follows[2]

$$D_x = \sum_n \left| \frac{E_{n,x}}{E_{n,i}} - 1 \right| / \Delta f$$

where $E_{n,x}$ is the maximum field amplitude in n-th cell perturbed by $\pm\Delta f$ as described above, and $E_{n,i}$ is the maximum field amplitude in n-th cell for unperturbed case. $E_{n,x}$ and $E_{n,i}$ are normalized by the average of

Table 1 model tanks parameters

drift tube diameter	(cm)	10	6	4
frequency	(MHz)	440	440	500
stem and post coupler diameter	(cm)	1.5	1.5	1.0
tank inner diameter	(cm)		44	
tank length	(cm)		54	
cell length	(cm)		6	
cell number			9	
drift-tube-to-wall spacing /one-quarter wave length		1.0	1.11	1.33

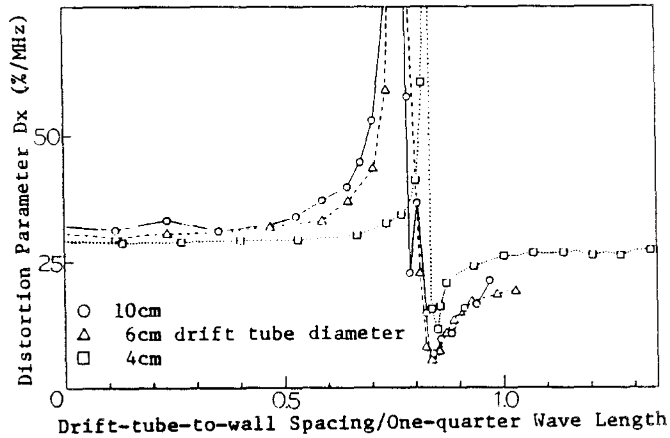

Fig.1 Distortion parameter, Dx, as a function of the ratio of drift-tube-to-wall spacing to $\lambda/4$

middle three cell data, 4th, 5th and 6th. Fig.1 shows distortion parameters as a function of the ratio of post coupler length to $\lambda/4$. As the ratio of drift-tube-to-wall spacing to $\lambda/4$ increases, the range of field stabilization becomes narrower. This means that field stabilization with post coupler becomes difficult.

Equivalent Circuit[3]

The ratios of post coupler length to $\lambda/4$ at minimum Dx in each model were almost same. The resonance of post coupler itself seems more important than the resonance due to post coupler inductance and capacitance between a post coupler and a drift tube. The resonance of post coupler itself is due to the inductance of a post coupler and the capacitance between a post coupler and a tank inner wall. The equivalent circuit of DTL with post couplers is shown in Fig.2. L_0, L_1 and L_2 are inductances of a half drift tube, a half stem and a half post coupler respectively. C_0, C_1, C_2 and C_3 are capacitances between adjacent half drift tubes, a half drift tube and a tank wall, a half drift tube and a half post coupler, a half post coupler and a tank wall respectively. M_0, M_1 and M_2 are mutual inductances between half drift tubes, half stems and half post couplers respectively. Because post couplers alternate side to side, we neglect the mutual inductance between adjacent post couplers and consider one between next adjacent post couplers.

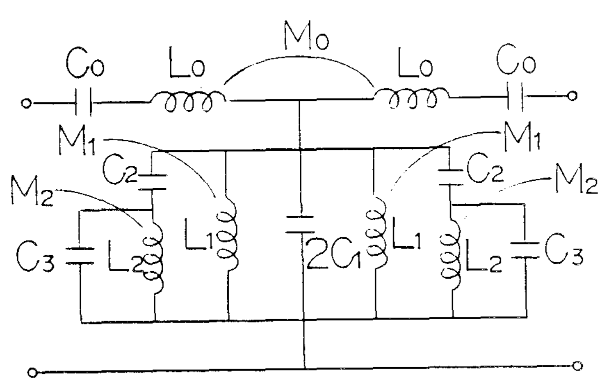

Fig.2 Equivalent circuit of DTL with post coupler

As phase shift is θ in this equivalent circuit, dispersion relation is as follows,

$$\sin^2\frac{\theta}{2} = \left(1+k_0\cos\theta - \frac{\omega_0^2}{\omega^2}\right)\times$$
$$\left\{\frac{L_0}{L_1(1-k_2^2)}\left[\frac{\omega^2}{\omega_1^2}(1-k_1^2) - 1 + k_1\cos\theta\right]\right.$$
$$- \frac{L_0}{L_2}\left[\frac{\omega_3^2}{\omega^2}\left(\left(\frac{\omega_2^2}{\omega^2}+\frac{\omega_3^2}{\omega^2}\right)(1-k_2\cos 2\theta) - \frac{\omega_2^2}{\omega^2}\frac{\omega_3^2}{\omega^2}\right)\right.$$
$$\left. + \frac{\omega_2^2}{\omega^2}\frac{\omega_3^2}{\omega^2}(1+k_2\cos 2\theta) - \left(\frac{\omega_2^2}{\omega^2}+\frac{\omega_3^2}{\omega^2}\right)(1-k_2^2)\right]$$
$$\left. / \left[\left(\frac{\omega_2^2}{\omega^2}+\frac{\omega_3^2}{\omega^2} - \frac{\omega_2^2}{\omega^2}\frac{\omega_3^2}{\omega^2}\right) - k_2^2\left(\frac{\omega_2^2}{\omega^2}+\frac{\omega_3^2}{\omega^2}\right)^2\right]\right\}$$

where

$k_0 = M_0/L_0$, $k_1 = M_1/L_1$, $k_2 = M_2/L_2$

$\omega_0^2 = 1/L_0C_0$, $\omega_1^2 = 1/L_1C_1$, $\omega_2^2 = 1/L_2C_2$, $\omega_3^2 = 1/L_2C_3$

ω_0^2, ω_1^2 are constant and ω_2^2, ω_3^2 vary as a function of post coupler length. We calculate the dispersion curves changing the post coupler length and investigate the field stabilization.

L_0, C_0, M_0 and C_1 are calculated from 0, $\pi/2$ and π mode frequencies and stored energy of SUPERFISH results. L_1 , L_2 are calculated as inductances of a bar, and M_1 , M_2 as mutual inductances between parallel bars. We calculate the frequencies of the model of Fig.3 (a) with SUPERFISH to evaluate C_2 and C_3 on the base of the equivalent circuit of Fig.3 (b).

We define the stabilization parameter, which indicates effectiveness of field stabilization for dispersion curve, as follows[4]

$$S = \left(\frac{\Delta\omega_a}{\Delta\theta}\right)^2_{\theta=0}\frac{1}{\omega_a^2-\omega_c^2}$$

where ω_a is accelerating frequency and ω_c is coupling frequency. A larger S is required for field stabilization. Fig.4 shows 1/S as a function of the ratio of post coupler length to $\lambda/4$ for each model. Each figure shows minimum of 1/S at the length of almost 0.8 times $\lambda/4$. This agrees with the measurements.

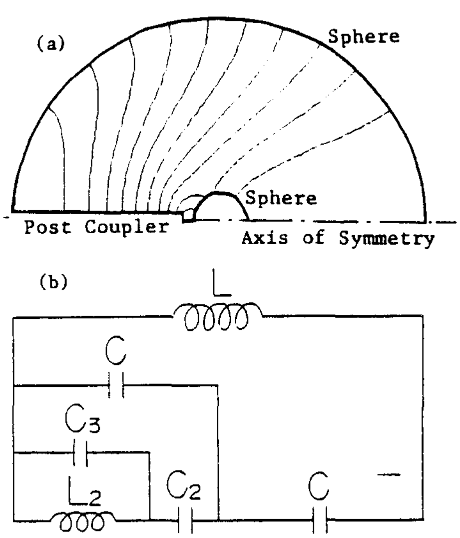

Fig.3 (a) Model to calculate the capacitances between a post coupler and a drift tube, a post coupler and a tank wall. A drift tube and a tank are represented by inner and outer spheres for simplification.
(b) Equivalent circuit of the model. L is inductance of outer sphere, and C is capacitance between inner and outer spheres. C_2, C_3 and L_2 are same as in Fig.2.

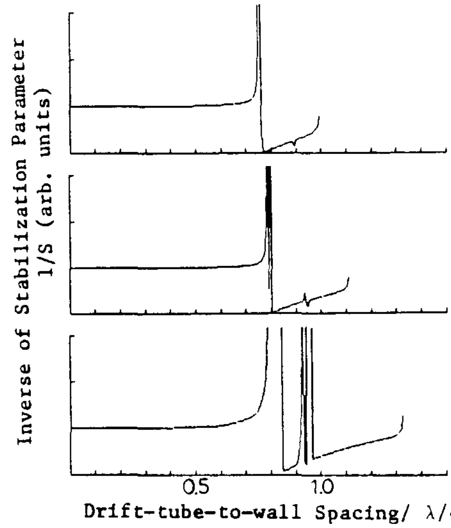

Fig.4 Inverse of stabilization parameter, 1/S, as a function of the ratio of drift-tube-to-wall spacing to $\lambda/4$ for 10cm, 6cm and 4cm drift tube diameter respectively from the top

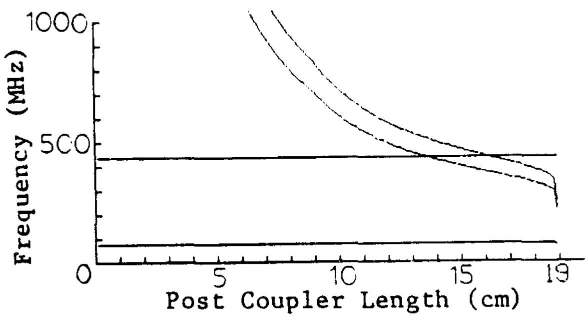

Fig.5 Changes of resonant frequencies of equivalent circuit for 6cm drift tube diameter

Frequencies of Modes

From the dispersion relation four resonant frequencies are calculated for certain post coupler length. Fig.5 shows the calculated resonance frequency as a function of the post coupler length of 6cm drift-tube diameter model.The shorter post coupler makes frequencies of the modes of post coupler much higher than that of accelerating mode. As the post coupler length becomes longer,the frequencies of post coupler modes decrease and couple with accelerating mode at a proper post coupler length. The field will be stabilized at this point.

Fig.6 shows the measured frequencies of various modes in the model cavity with 6cm diameter drift tube as a function of post coupler length. In the figure E// and E⊥ represent the mode of electric field parallel and perpendicular to stem respectively. As the post coupler length becomes longer, the frequency of each mode goes down, and a mode mixes with a certain mode and exchanges and separates. For example, the frequency of TM_{012} mode is ~675MHz at first and seems to go down drastically above the post coupler length of 6cm. TM_{012} mode mixes with $TE_{212E//}$ mode coming down and exchanges with $TE_{212E//}$ mode. TM_{012} mode (well defined) reappears at the frequency of ~680MHz and the frequency of $TE_{212E//}$ mode goes down.

There exists a severely distorted range before stabilization with increasing the post coupler length.

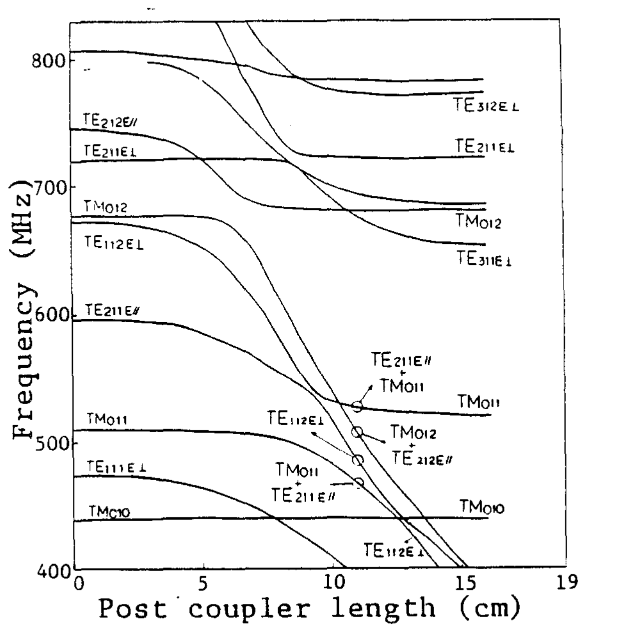

Fig.6 Frequency shifts of 6cm drift tube diameter model cavity as a function of post coupler length

This is explained as follows. TM_{011} mode mixes with $TE_{211E//}$ mode and reappears at higher frequency than that of zero post coupler length. The going down frequency of TM_{011} mode makes the mode spacing between TM_{010} and TM_{011} narrow, and the field distribution has a tilt. After that, the TM_{011} mode separates from TE_{211E} to achieve the stabilization. From this mode spectrum point of view, there is no explanation to the unstabilized situation for the post coupler length of more than 15cm. (Although the mode spacing is still large.)

Stabilization with Strip Line[5]

In the model of 4cm drift tube diameter, the field stabilization range of post coupler length was limited and it was difficult to stabilize the field with post couplers. So we tried to get stabilization with strip line instead of post couplers. The $\lambda/2$ mode strip line as Fig.7 was installed in DTL. The length of strip line was slightly shorter than $\lambda/2$ and the gap between the tuner and strip line was variable, so that the resonance of strip line was adjustable around the accelerating frequency.

At first field distributions were measured with 15mm height strip line. Fig.8 shows the distortion parameter Dx. Dx was a little smaller than Dx of no strip line. 15mm height strip line was thought to be low that the coupling would be weak. Then 30mm height strip line was installed. The almost same minimum Dx was obtained as in the case of post couplers, and there was enough adjustable range. But the model tank was so short that only $\lambda/2$ strip line could be installed. The

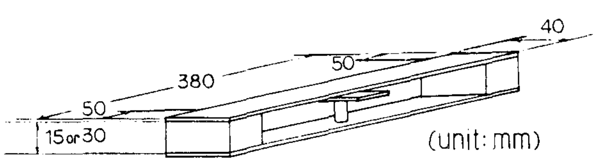

Fig.7 A schematic view of strip line

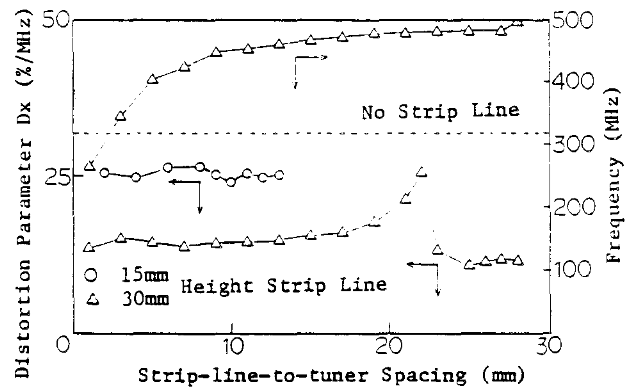

Fig.8 Distortion parameter, Dx, and frequency as a function of strip-line-to-tuner spacing

sets of $n\lambda/2$ strip lines which are shifted $\lambda/4$ each other could stabilize the field distribution of a larger tank.

Conclusions

As the drift-tube-to-wall spacing increases, it becomes more difficult to stabilize the field with post couplers. But at the point of stabilization the ratios of post coupler length to $\lambda/4$ are almost same regardless of the drift-tube-to-wall spacing. And from the mode spectrum we can obtain the useful data for stabilization and distortion of the field with post coupler.

References

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