A PRELIMINARY STUDY OF
THE TS ZERO MODE AND ITS ROLE IN FIELD FLATTENING
OF MULTI AND TUNABLE STEM ACCELERATING STRUCTURES*

S. Giordano and J. Hannwacker
Brookhaven National Laboratory
Upton, New York

Introduction

The interest in building high energy high intensity proton linear accelerators, has resulted in the development of a new generation of rf structures. Not too many years ago, Alvarez drift tube structures were considered the best choice for low β's, while slotted iris and cloverleaf structures excelled at high β's. The choice of these structures was based primarily on high shunt impedance. In the above structures the accelerating mode is at the end of the passband where the operating characteristics are directly related to the bandwidth of the structure. In order to improve the operating characteristics, that is, to reduce amplitude and phase variation along the tank due to beam loading, the slotted iris[1,2] and cloverleaf[3,4] structures should be operated with the largest possible bandwidth consistent with good shunt impedance.

It was soon recognized that the π/2 mode was less sensitive to tuning errors, and correspondingly smaller amplitude and phase variations as compared to a zero or π mode, but had the disadvantage of a much lower shunt impedance. Two new π/2 mode structures having a high shunt impedance were developed; the side coupled[5] and alternating periodic structures.[6] The reduction of amplitude and phase variations of these two structures as compared to the cloverleaf and slotted iris structures, can only be described as spectacular.

For low β's, the multistem[7,8] drift tube structure was devised, which has essentially the same high shunt impedance as the Alvarez structure, but with the additional characteristic of reducing the field variation due to a perturbation by a factor of 10 to 100 as compared to the Alvarez structure. The multistem structure also reduces the phase variations along the tank by a factor of 3 to 5 due to increased mode spacing.

Alternating tunable stems[9] were devised which also have the ability of reducing the amplitude variation as the multistem. The alternating tunable stem structure does not have as large a mode spacing as the multistem.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

The purpose of this paper is to compare multistem and alternating tunable stem structures and to understand their behavior.

Multistem and Alternating Tunable Stem Structures

Some of the operating characteristics of multistem structures have been previously reported.[7,8] A transverse resonance (lower passband), associated with the stem and drift tubes must be matched to the TM_{01} passband in order to achieve an improvement in the field characteristics of the tank. There is a similar transverse resonance associated with alternating tunable stem structures. The difference that exists between the above two structures may be seen by inspecting the dispersion curves and corresponding field amplitude vs. frequency perturbation characteristics. The differences in the measured characteristics of the above two structures provides an insight into the mechanism of how and why these structures work, thereby giving a basis for evolving a theory.

Dispersion Curves and Tank Flattening Characteristics

A comparison between the dispersion curves for multistem and alternating tunable stems at 30 MeV and 84 MeV will now be made.

Figure 1 is a set of dispersion curves measured on a 30 MeV linac model operating in the neighborhood of 850 MHz. The plots shown in Fig. 1 are for three different structures: 1) single stem Alvarez showing the TM_{01} passband (the associated TS passband is much lower in frequency and is not indicated), 2) alternating tunable stem showing both the TM_{01} and TS_{10} passbands, 3) optimum compensated multistem structure. It is of interest to note that there is a considerable difference in the shape of the dispersion curve in the region of the TM_{010} mode for the multistem structure as compared to the alternating tunable stem structure.

Let us now consider Figs. 2 and 3, where a fixed frequency perturbation is placed at the end of a 30 MeV tank, and the H_θ field is then measured and plotted for a single stem Alvarez and compared to a multistem and an alternating tunable stem structure. We see that for both the multistem and the alternating tunable stem structures the field remains essentially flat as compared to the single stem Alvarez structure.

Correspondingly, for 84 MeV we have Figs. 4, 5, and 6 respectively, and the tank flattening results are essentially the same as the 30 MeV case.

It is interesting to note in both Figs. 1 and 4, comparing the one stem Alvarez structure with the alternating tunable stem structure that there is essentially no change in the TM_{01} dispersion curve. For the multistem structure, we find in Figs. 1 and 4 that there is a considerable change in the TM_{01} dispersion curve. The multistem structure results in a much larger mode spacing, or bandwidth, than the tunable stem structure at both 30 and 84 MeV.

Development of a Theory

A closer examination of Figs. 4 and 5 for 84 MeV shows that although we have optimized both cavities to reduce the average field variation along the tank as compared to a single stem Alvarez structure, the alternating tunable stem structure has a ripple as compared to the multistem structure. At 30 MeV, Figs. 2 and 3, we note that the ripple is not as pronounced as the 84 MeV case.

Let us now examine the dispersion curves in Figs. 1 and 4, and see if this ripple can be correlated to the dispersion characteristics. For the multistem case, we see that there is a considerable change in the TM_{01} dispersion curve as compared to a one stem Alvarez structure, indicating a large coupling coefficient between the lower TS passband and the TM_{01} passband.

For the case of the alternating tunable stem structure, we see from Fig. 1 that for the 30 MeV, there is a change in the TM_{01} dispersion curve and that for the 84 MeV case, Fig. 4, there is essentially no change in the TM_{01} dispersion curve.

From the above, we can then conclude that the coupling between the TM_{01} and TS_{10} passbands is very large for the multistems at both β's being considered; and for alternating tunable stems at 30 MeV the coupling is somewhat less than the multistems, but at 84 MeV the alternating tunable stem has essentially zero coupling.

It can be concluded from the above, that tank stiffening is independent of the shape of the dispersion curves, since both the multistem and alternating tunable stem structures give the same average field tank stiffening, but with reduced coupling between passbands there is an increased ripple in the field.

We must now look for a common mechanism by which to explain tank stiffening for both structures. Let us first consider a single stem Alvarez structure where there are no TS_{10} modes in the vicinity of the TM_{010} mode. If a frequency perturbation is placed in the Alvarez structure, a field tilt is observed.

For the case of the multistem or alternating tunable stem structures driven at the operating frequency, there will be in addition to the TM_{010} mode a second mode, which we will postulate as being a TS_{100} mode which exists only in the presence of a frequency perturbation. When the multistem or alternating tunable stem structure is optimally compensated, the TS_{100} contributes a field that is exactly equal and opposite to the field tilt of the TM_{010} mode, consequently, the average field remains flat.

In order to accept the above explanation, we must establish two factors: 1) that the TS_{100} mode exists and is excited by a perturbation, 2) that the TS_{100} mode has field components similar to the TM_{010} mode.

The TS_{100} Mode

In a linac cavity, excited in the TM_{010} mode with no frequency perturbation, only the TM_{010} field exists. When a perturbation is placed in the cavity, we have postulated that the TS_{100} mode is excited, but if we attempted to measure the TS_{100} mode under such conditions, we would find that the TM_{010} fields are very much greater than TS_{100} fields, and as such it would be difficult to identify the TS_{100} mode.

As it has been previously reported for multistem structures,(7,8) the TS_{100} mode can be established with a cutoff section as shown in Fig. 7a. It should be pointed out that the cutoff section suppresses the TM_{010} mode. The cutoff sections are not perfect open circuit boundaries, and as such have a slight distortion or mismatch at the ends of the cavity for the TS_{100} mode resulting in a tilt of the E_r field of this mode. Measuring the field components of the TS_{100} mode, we find that there are predominantly E_r fields, and because of the mismatch at the ends of the cavity we also have an E_z component of field on the axis. A perturbation was then placed in the cavity as shown in Fig. 7a. Differences between the E_z fields with and without the perturbation clearly showed that the perturbation was responsible for the introduction of an additional E_z component. It is this E_z component, that is introduced by the perturbation, that exactly compensates the variation of the E_z field of the TM_{010} mode. At this time it is a little difficult to prove that there is a one-to-one relationship, but further measurements are in progress. The important concept here is that the perturbed TS_{100} mode does introduce an E_z component. It should be pointed out that there is a corresponding H_θ component associated with the E_z component.

For the multistem structure, a simple extension of the cavity forms a very effective cutoff section, since the fields on the last drift tube and stems can be likened to a TE_{41} mode (for a 4-stem drift tube). The operating frequency is well below the cutoff frequency of the TE_{41} mode, and therefore acts as an effective open circuit.

For the alternating tunable stem structure, the cutoff section is not as simple as for the multistem cavity. Due to the fact that the fields of the TS_{100} mode for the alternating tunable structure can be likened to a TE_{11} mode, a simple extension of the cavity ends does not provide a proper open circuit termination. For the alternating tunable stem cavity we used a resonant section as shown in Fig. 7b. It was then possible to excite a TS_{100} mode for the alternating tunable stem, but here again due to a mismatch at the boundary of the open circuit field distortions were introduced as in the case for the multistem structure.

For the alternating tunable stem, we found that the H_θ fields measured at the wall were concentric with the stems and having an alternating maximum field and zero field between stems on the same side of the cavity. On the opposite side, the maximum and zero fields were interchanged. This clearly showed that the TS_{100} mode is skewed. Measurements were also made to determine the excitation of an E_z field, and the results were similar to those obtained with the multistem cavities.

Summary

It now has been shown by tank field measurements that the effects of a perturbation can be compensated by employing either a multistem or alternating stem structure. By comparing the dispersion curves of the two structures at 30 MeV and 84 MeV, the improvement in tank flattening could not be explained in terms of these dispersion curves. We then proceeded to postulate that for either the multistem or alternating tunable stem structure that when a perturber is introduced into the cavity, the TM_{010} mode is tilted but simultaneously the TS_{100} mode is excited, noting that the fields of this mode are similar to but having the opposite sense of the fields of the TM_{010} mode. Consequently, the fields of the TS_{100} mode will exactly compensate for the change in the fields of the perturbed TM_{010} mode when the proper stem parameters are chosen. Other measurements are presently in progress, in which we hope to completely verify the proposed theory.

New Structure

Having established the criteria of the necessity of the TS_{100} mode in compensated structures and having an insight into the fields that exist in Alvarez structures, new cavity designs can be generated having the ability of reducing the effects of frequency perturbation.

A modification can be made on the alternating tunable stem design. Figure 8 shows the tunable stems rearranged so that the tunable stems are all directly opposite the support stem. The dispersion curve for this new structure is shown in Fig. 9 and its ability to maintain a flat field in the presence of a frequency perturbation is shown in Fig. 10. The TS modes shown in Fig. 9 have a very narrow bandwidth as compared to the other structures so far considered. This implies extreme critical tuning and would not be practical for an accelerating structure.

References

1. S. Giordano,"Measurements of Iris Loaded Waveguide," Minutes of the Conference on Linac Accelerators, Yale University, October, 1963, pp.153-170.

2. S. Giordano, "Characteristics of Slotted Irises," Minutes of the Conference on Linac Accelerators, MURA, July, 1964, pp. 60 - 74.

3. E. Knapp, "Accelerating Structures at Los Alamos," Minutes of the Conference on Linac Accelerators, Yale University, October, 1963, pp. 131 - 152.

4. E. Knapp, "800 MHz Rf Structures," Minutes of the Conference on Linac Accelerators, MURA, July, 1964, pp. 31 - 59.

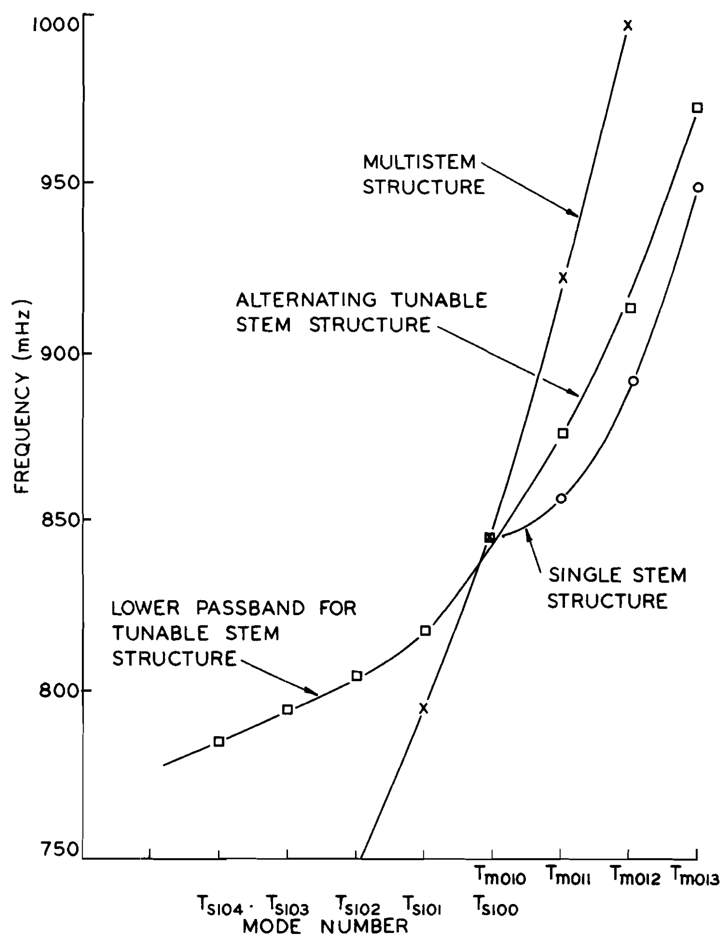
5. E. Knapp, "800 MHz Rf Structures," Minutes of the Conference on Linac Accelerators, MURA, July, 1964, pp. 31 - 59.

6. S. Giordano, "Some New Radio Frequency Structures," IEEE Trans. Nucl. Sci., NS-12, No. 3, 213 (1965).

7. S. Giordano, "A New Multistem Drift Tube Standing Wave, Zero Mode Proton Accelerating Structure," Internal Report BNL AGSCD-7, February, 1966.

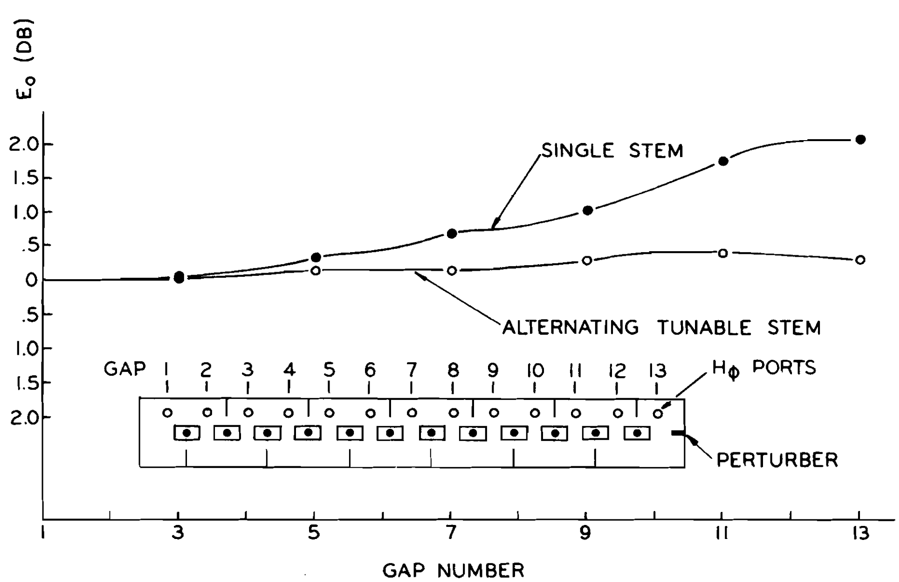
8. S. Giordano and J. Hannwacker, "Measurements on a Multistem Drift Tube Structure," Proceedings of the 1966 Linac Accelerator Conference, October, 1966, Los Alamos, pp. 88 - 91.

9. E. Knapp, et al. Internal Report LASL, June 2, 1967.

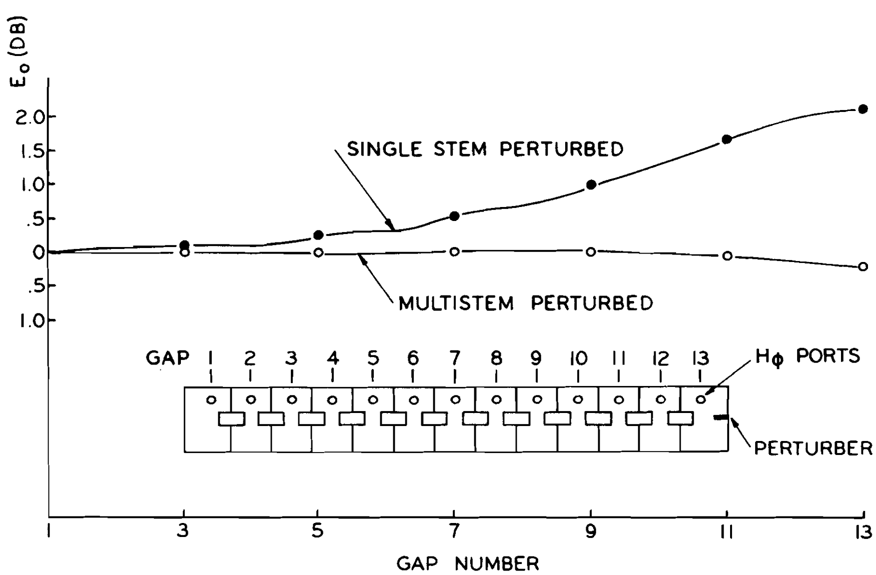


1. Dispersion curves for the following rf structures at 30 MeV:

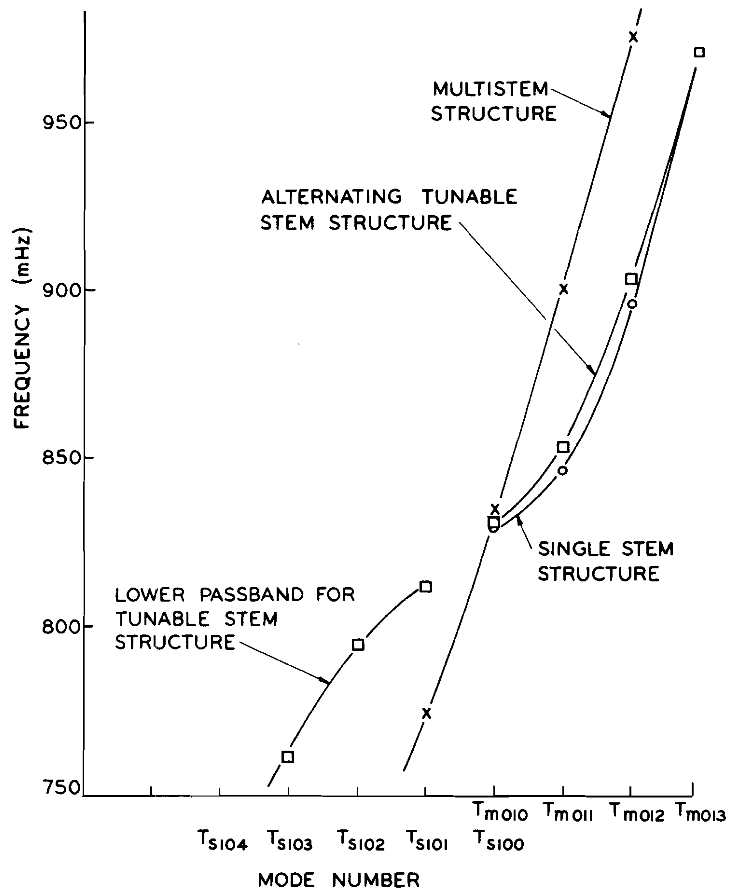
   a) Single stem.
   b) Multistem.
   c) Alternating tunable stem.



2. Tank stability vs. frequency detuning perturbation for a single stem and alternating tunable stem linac cavity at 30 MeV.

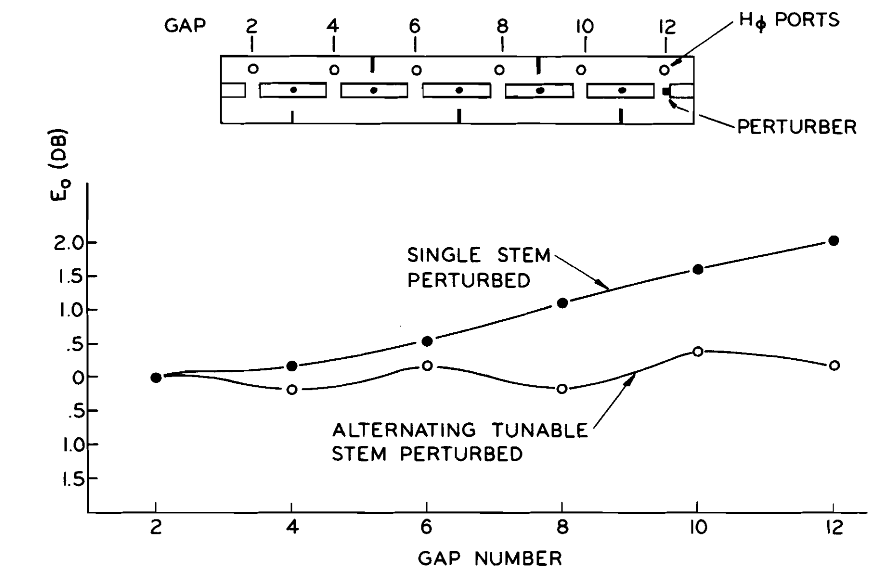


3. Tank stability vs. frequency detuning perturbation for a single stem and a multistem linac cavity at 30 MeV.

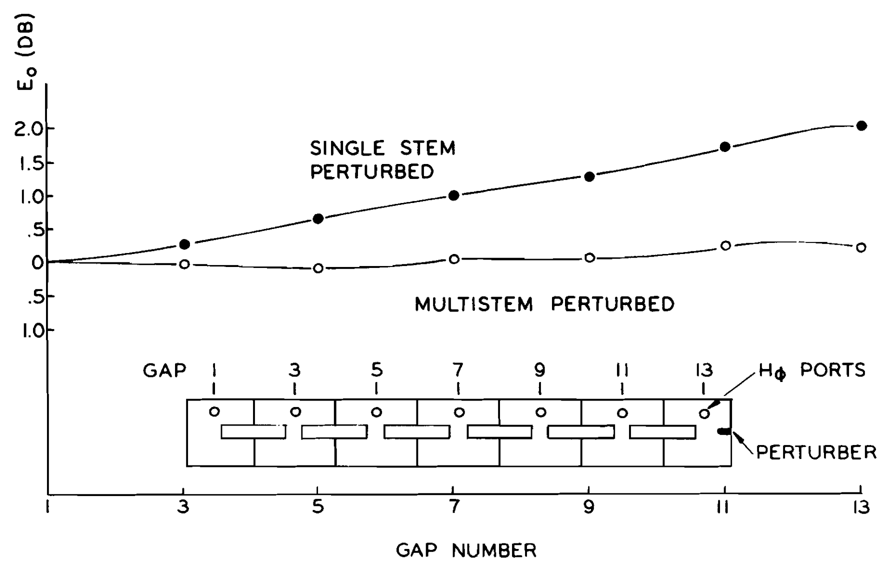


4. Dispersion curves for the following rf structures at 84 MeV:

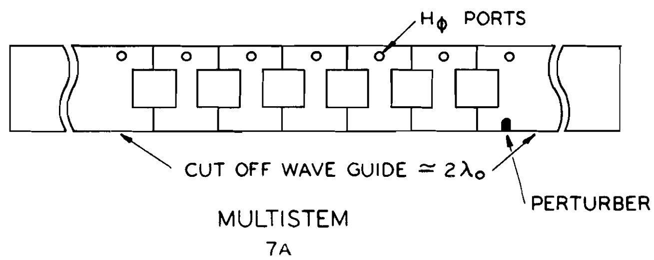
a) Single stem.
b) Multistem.
c) Alternating tunable stem.



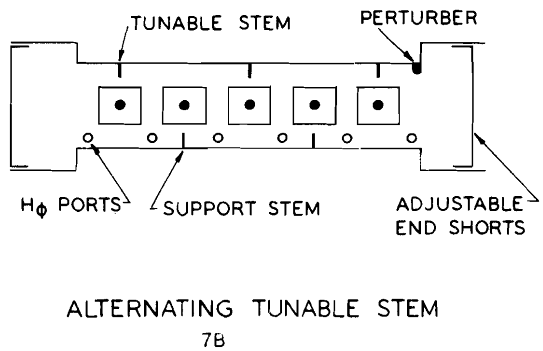
5. Tank stability vs. frequency detuning perturbation for a single stem and alternating tunable stem linac cavity at 84 MeV.



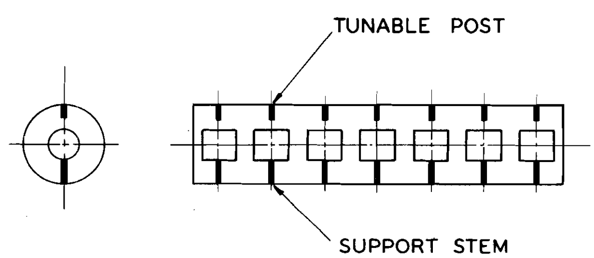
6. Tank stability vs. frequency detuning perturbation for a single stem and a multistem linac cavity at 84 MeV.



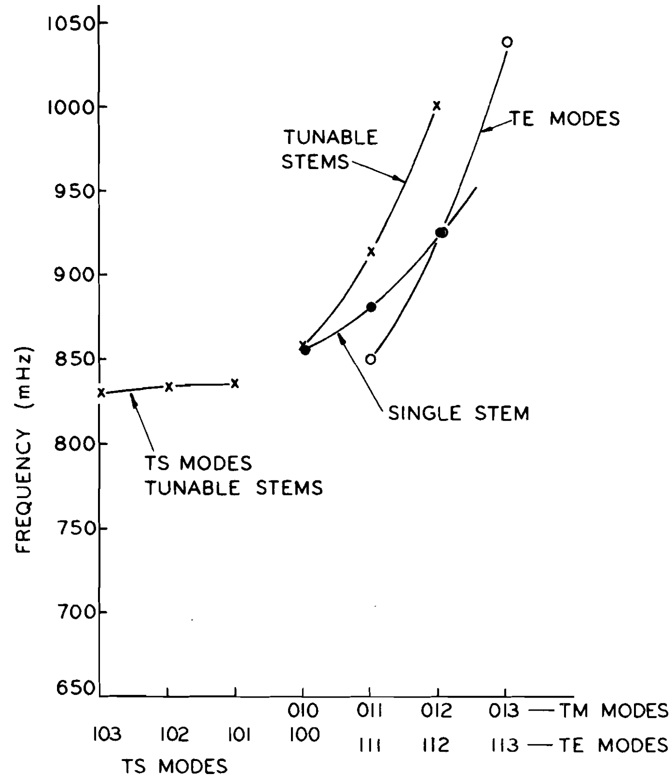
7\. a) Waveguide end sections to measure the characteristics of the TS_{100} mode for the multistem structure.



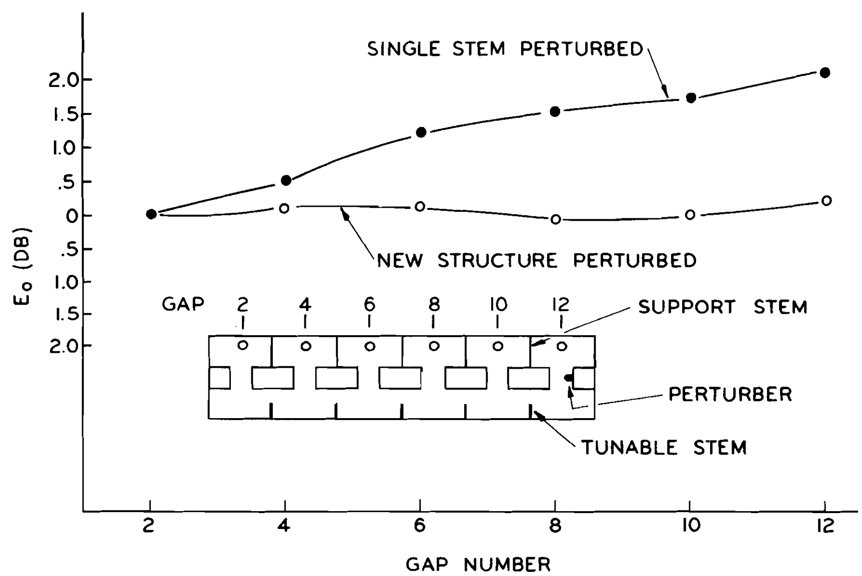
b) Waveguide end sections to measure the characteristics of the TS_{100} mode for the alternating tunable stem structure.



8\. A new rf drift tube structure having very high tank stability against frequency detuning errors.



9. Dispersion curves for a single stem cavity and for the linac cavity shown in Fig. 8.



10. Tank stability vs. frequency detuning perturbation for a single stem cavity and for the linac cavity shown in Fig. 8.