TUNING EXPERIENCE WITH THE FMIT SCALE-MODEL DRIFT-TUBE LINAC*

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Summary

A scale model of the Fusion Materials Irradiation Test Facility (FMIT) 80-MHz drift-tube linac (DTL) was constructed to investigate the tuning procedure. Figure 1 shows this structure: a post-coupled[1] Alvarez with couplers located on alternate drift tubes. The model DTL has 16 cells and was constructed to have the accelerating mode at 367 MHz. The mode spectrum was measured for various post penetrations, and field profiles of the modes were recorded. The field profiles were measured by using a beadpull apparatus, together with an automatic data-acquisition system. Tilt-sensitivity measurements were performed to find the optimum post penetrations for stabilizing the accelerating mode.

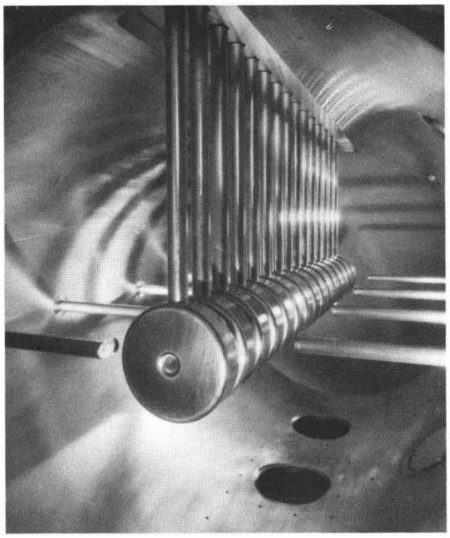

Fig. 1. Photograph of the FMIT scale-model DTL.

Introduction

Optimum stabilization of the field distribution against tuning errors for a resonantly coupled accelerator structure is obtained when all the resonant couplers are tuned to the same frequency as that of the accelerating mode. This tuning is achieved in biperiodic structures by adjusting all the couplers in a systematic way so that the stop band is closed. For a quasi-periodic structure, like a post-coupled DTL, closing the stop band results in the post-coupler frequencies being too high at one end of the structure, too low at the other end of the structure, and correct only at some intermediate locations. The result is that the structure is optimally stabilized in only the central region. Because the purpose of the post couplers is to stabilize the field distribution against the effects of tuning errors, a practical tuning technique is to adjust the post couplers until the field distribution is sufficiently insensitive to deliberately introduced tuning errors.

For a structure with post couplers every nth drift tube, the post couplers must be placed starting at the nth drift tube and ending on the nth drift tube from the other end to insure correct boundary conditions for the coupling mode. This implies that there should be a multiple of n accelerating gaps in the structure.

Field Ratio Method for Post-Coupler Tuning

In a truly biperiodic structure, coupled-circuit-model calculations show that if one end cell is perturbed by Δf_1, and the other end cell is perturbed by $-\Delta f_1$, the resonant frequency is unchanged to first order; and the field distribution is tilted linearly with a slope proportional to $\Delta f_1 \times \Delta f_{sb}$, where Δf_{sb} is the stop band width. Reversing the sign of the perturbation reverses the sign of the tilt. Further calculations show the cell-to-cell amplitude error to be proportional to $\Delta f_1 \times \Delta f_{cc}$, where Δf_{cc} is the tuning error of the coupling resonator between the two cells under consideration. This makes it possible to tune structures such as the post-coupled DTL, where the stop band is not a useful measure of the coupling-resonator frequency.

There are two components to the field distribution error: a geometrical part resulting primarily from errors in the position of drift-tube stems and post couplers with respect to the drift tube, and a tuning-related part that depends on accelerating cell frequencies and post-coupler frequencies. The geometrical part of the field distribution error may be cancelled by measuring the field distributions from two different sets of end-cell perturbations. One field distribution corresponds to the perturbation obtained by decreasing the drift-tube gap on one end of the structure and increasing the gap on the other end to restore the operating frequency. The other field distribution corresponds to a perturbation of similar magnitude but opposite direction. Forming a cell-by-cell ratio of these two field distributions cancels the geometrical part, leaving only the tuning-related part. When the post couplers are adjusted so that this ratio is equal for all cells, the field distribution is stabilized. Field measurements with no end-cell perturbations will now reveal the geometrical part of the field distribution errors. These errors are removed by rotating the post-coupler tabs until the desired field distribution is achieved.

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Post-Coupler Tuning Procedure

1. Set each post coupler to the same length, and orient it so that it is symmetric about a vertical plane through its axis.
2. Keeping all post couplers the same length and, without rotating them, set their penetration either to close the stop band or to noticeably reduce the tilt sensitivity in some portion of the structure.
3. Adjust the penetration of each post coupler, in proportion to the measured tilt sensitivity at its location, until it has been stabilized.
4. Adjust the rotation of the post coupler until the stabilized field distribution fits the desired theoretical pattern.
5. Recheck the tilt sensitivity to verify that rotating the post couplers did not appreciably affect the structure stability.

Tilt-Sensitivity Measurement Procedure

1. Detune one end cell by some predetermined amount, as measured by observing the change in the accelerating-mode frequency, or by some mechanical means, such as counting turns on a screw adjustment of the end drift-tube's longitudinal position.
2. Detune the other end cell, so as to restore the accelerating-mode frequency to its original value.
3. Measure the field distribution by the beadpull technique. Either the peak amplitude or the average amplitude may be used, as desired. For consistency, the field amplitudes should be normalized for unity average value.
4. Reverse the perturbation of Step 1. If the size of the perturbation is determined by observing the accelerating-mode frequency, restore both end cells to the unperturbed condition before setting up the new perturbation.
5. Restore the accelerating-mode frequency as in Step 2.
6. Measure and normalize the field distribution by the same technique as that used in Step 3.
7. Form the ratio of the amplitudes measured in Steps 3 and 6 on a cell-by-cell basis.
8. If the same end-cell perturbation is used consistently, the tilt sensitivity at each post coupler is proportional to the difference in amplitude ratio of the two cells on either side of the post coupler. This definition applies, whether the post couplers are located at every drift tube or at every nth drift tube.

Mode Spectrum

The mode spectrum for both the post-coupler modes and the TM_{01} modes were recorded as a function of the spacing G--the gap between the drift-tubes and the post-couplers. In each case, all the post couplers were set for the same spacing G. Mode identification was done using beadpulls. The plot of the mode spectrum is shown in Fig. 2. The curves show how the post-coupler passband is very sensitive to the value of G. The curve for G = 1/2 in. seemed to close the stop band and this value of G then was used as a starting place for the next step in the tuning procedure--the tilt-sensitivity measurements.

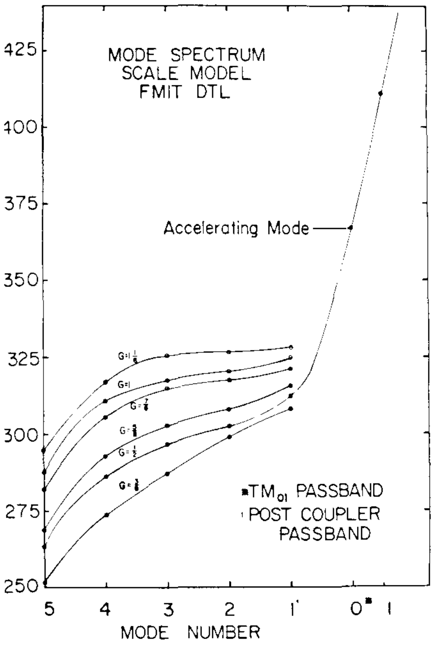


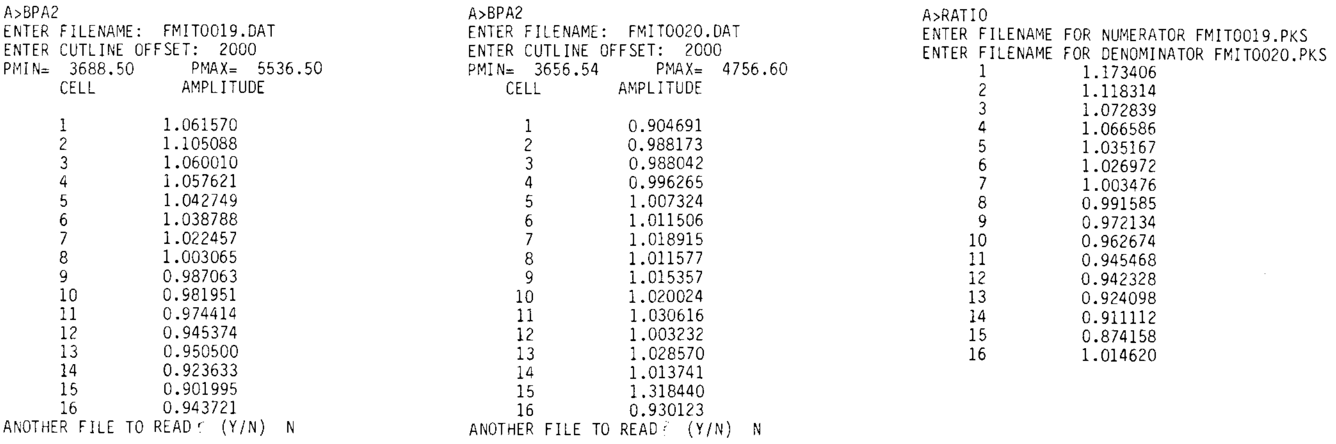
Fig. 2. Mode spectrum for the FMIT scale-model DTL.

Tilt-Sensitivity Measurements

The tilt-sensitivity measurements were performed, using the previously described procedure. In our case, the detuning was done using adjustable end drift tubes that were movable by a screw adjustment. Peak fields were measured in each cell, using a beadpull apparatus, and then were normalized for unity average value. A ratio then was made on a cell-by-cell basis for the cases of perturbation in each direction. Figure 3 shows a computer printout for the measured normalized peak field in each cell. The first list is for a tilt in one direction, the second for a tilt in the opposite direction, and the last is the ratio of the first two. This is the case for G = 3/8 in. All post couplers had this same value. The plot of the ratio is shown in Fig. 4. This measurement was done for values of G ranging from 0.1 to 1.0 in. No significant improvement in the tilt sensitivity could be found in this range of G.

Conclusion

The difficulty in obtaining a satisfactory adjustment of the post couplers is believed to be caused by the structure's shortness and its low beta. With only 16 accelerating gaps, the structure's field distribution is already fairly insensitive to perturbations or tuning errors. In low-beta structures, the cell-to-cell variations are such that correct adjustment for each post could require a different value for G. Coupled-circuit analysis shows that the tuning of the coupling resonator is more critical when the accelerating-cell to accelerating-cell coupling is much stronger than the coupling-cell to accelerating-cell coupling. Figure 5 shows a simple coupled-resonator



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     3            1.060010
     4            1.057621
     5            1.042749
     6            1.038788
     7            1.022457
     8            1.003065
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     11           0.974414
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      5            1.007324
      6            1.011506
      7            1.018915
      8            1.011577
      9            1.015357
     10            1.020024
     11            1.030616
     12            1.003232
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      4             1.066586
      5             1.035167
      6             1.026972
      7             1.003476
      8             0.991585
      9             0.972134
     10             0.962674
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     12             0.942328
     13             0.924098
     14             0.911112
     15             0.874158
     16             1.014620
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Fig. 3. Computer printout of normalized peak-field amplitudes for each cell, and ratio for tilt-sensitivity measurement.

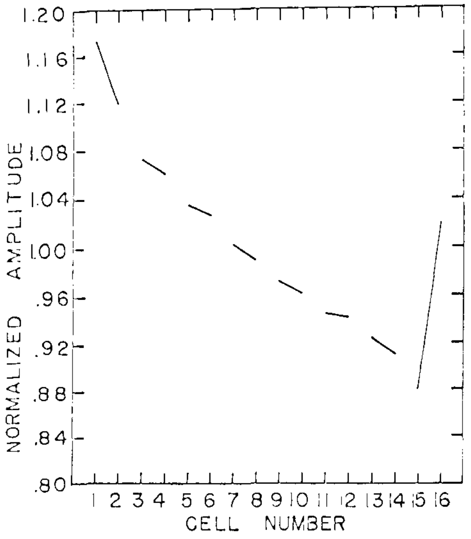

Fig. 4. Plot of normalized peak-field-amplitude ratio on cell-by-cell basis (G = 3/8 in.).

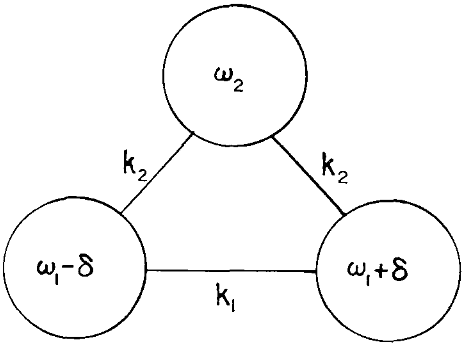

Fig. 5. Coupled resonator model for post coupler and accelerating cell.

model having some of the basic features of the DTL. The resonators labeled $\omega_1 - \delta$ and $\omega_1 + \delta$ represent two accelerating cells and ω_2 represents a post coupler. The coupling coefficients are k_1 and k_2. For this model the tilt-sensitivity reduction factor r as a function of ω_2 is given by

$$r = \frac{1 - \frac{\omega_2^2}{\omega_\pi^2}}{1 - \frac{\omega_2^2}{\omega_\pi^2} - \frac{k_2^2}{k_1}} ,$$

where

$$\omega_\pi = \frac{\omega_1}{1 + k_1} .$$

Thus, with $k_2 \ll k_1$, the resonant coupler is effective for only a small range of ω_2.

References

1. J. M. Potter, Los Alamos National Laboratory, "Post-Coupler Tuning Considerations for the NEN 45-MeV Linac," unpublished report.