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POST-COUPLER STABILIZATION AND TUNING OF A RAMPED-GRADIENT DRIFT-TUBE LINAC*

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Abstract

This paper reports low-power tuning and stabilization measurements on the Los Alamos Ramped-Gradient Drift-Tube Linac (RGDTL). The RGDTL is a 425-MHz, 1.87-m-long structure containing 29 drift tubes, 14 post couplers, 2 tuners, and 2 drive loops. The design calls for an axial electric field gradient that increases from 2.0 MV/m to 4.4 MV/m over 1.5 m for accelerating H^- from 2.07 to 6.67 MeV. Asymmetric post couplers adjacent to every other drift tube both stabilize and ramp the field. The two tuners provide 1.4 MHz of dynamic frequency adjustment around the frequency selected by a one-time trimming of two tuning bars that are bolted inside the tank alongside the drift-tube stems. Field measurements obtained by the bead-perturbation method determine how to adjust the post couplers for the desired ramp. Comparison of two field distributions for different deliberate frequency perturbations quantifies the structure's tilt sensitivity and indicates whether to tune the post coupler frequencies lower or higher with respect to the TM_{010} accelerating mode frequency.

Introduction

The principal goals of the tuning effort were to (1) tune the TM_{010} accelerating mode to 425 MHz, (2) achieve the ramped field distribution, and (3) stabilize the fields against tuning errors. Each of these tasks involves modification of one or more rf surfaces in the cavity. Dynamic tuners ultimately control the resonant frequency. Adjustment of the post-coupler[1] penetrations tunes the post couplers in frequency and, therefore, mainly affects the stability of the field distribution. Rotation of an asymmetric post coupler toward one end of the structure causes a local drop in the field on that side of the post coupler and a corresponding rise on the other side. Although this orientation adjustment mainly affects the field distribution, it also changes the resonant frequency slightly. Tuning is an iterative procedure of successive penetration and orientation adjustments that results in a stabilized and ramped field distribution. This paper reports the results of this low-power rf tuning and field stabilization work. A companion paper[2] describes measurements of the post-coupler magnetic fields in the RGDTL, and another paper[3] discusses the structure's mechanical design and its unique components.

Resonant Frequency

The design frequency of the TM_{010} accelerating mode is 425 MHz. A pair of longitudinal tuning bars bolt to the inside of the tank alongside the drift-tube stems. For tuning-bar heights between 1.0 and 4.0 cm, the cavity frequency increases about 2 MHz/cm. Two slug tuners provide 1.4 MHz of dynamic tuning around the frequency selected by trimming the height of the copper tuning bars. Final selection of the height awaited completion of other adjustments, such as post-coupler penetrations that also affect cavity frequency. A tuning bar height of 2 cm tuned the RGDTL to 425 MHz with the slug tuners at their nominal operating point of one-third of full penetration.

Field Distribution

Figure 1 shows the design field distribution for the RGDTL. The quantity plotted is E_0, the average axial electric field across each cell:

$$E_0 = \frac{1}{L}\int_0^L E(z)\,dz\,, \tag{1}$$

where E(z) is the longitudinal component of the axial electric field and L is the cell length. One of our goals in

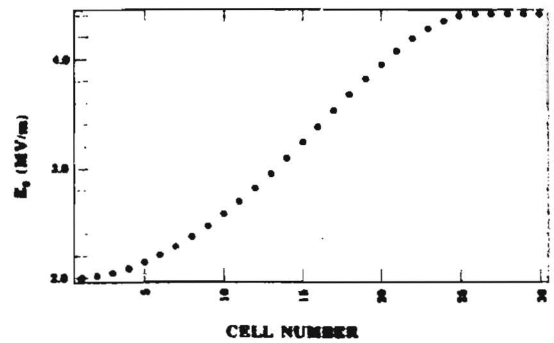

Fig. 1. Design axial field distribution for the RGDTL.

low-power tuning is to achieve this relative field distribution. To measure a field distribution, we use the bead-perturbation technique. A small metallic sphere pulled down the bore of the cavity at constant speed continually shifts the cavity frequency by an amount proportional to the square of the electric field integrated over the volume occupied by the bead. Our data acquisition program BEADPULL samples the frequency shift 9900 times during the 20 seconds it takes the bead to traverse the cavity. Such a measurement is shown in Fig. 2.

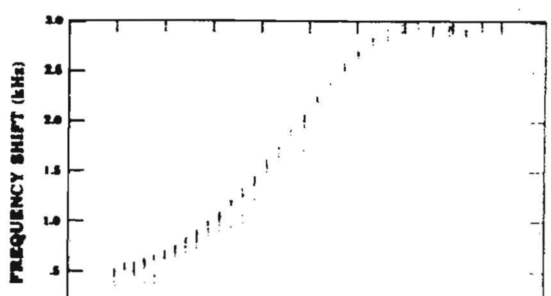

Fig. 2. Typical bead-perturbation measurement.

For comparison to the design field, the computer code DTLPLOT extracts quantities proportional to the peak field, the average field E_0, and the stored energy from the array

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of frequency-shift data over each cell. Of these three quantities, the peak field in each cell is the most accurately determined. For our measurement apparatus, typical reproducibility of these quantities is ±0.2% for the peak fields, ±1% for the average field integrals, and ±0.6% for the stored energy integrals. For the RGDTL, the errors are of this magnitude except near the low-energy (LE) end, where the signal-to-noise ratio is worst. For the first few cells, the errors tend to be two or three times larger than the typical values noted above.

An analysis of the peak-field data yields a more accurate determination of E_0 than the direct integration of the frequency shifts. The method uses the theoretical field distribution E(z) calculated by the code SUPERFISH. From a measurement of the peak field E_{peak} and from the calculated shape of the field, one can calculate the value of E_0. The procedure is to integrate the SUPERFISH shape over the portion of the cell occupied by the perturbing bead as the bead moves though the cell. From this calculation, one gets theoretical values of both E_0 and E_{peak}. Dividing the measured E_{peak} by the theoretical ratio E_{peak}/E_0 yields a value for E_0 that includes a correction for the size of the perturbing bead. This correction is about 1.7% on the LE end and about 1.0% on the high-energy (HE) end of the RGDTL. Figure 3 shows the final distribution of E_0 for the RGDTL obtained by this method given as a percentage relative to the average of E_0 over all cells; Fig. 4 shows the same data divided by the design fields. Perfect tuning corresponds to all points lying on the 100% line. Therefore, most of the cells have a relative field within ±0.5% of the design field. The fields in the two end cells are ~1.2% high. The data shown are averages of five separately analyzed bead-perturbation measurements.

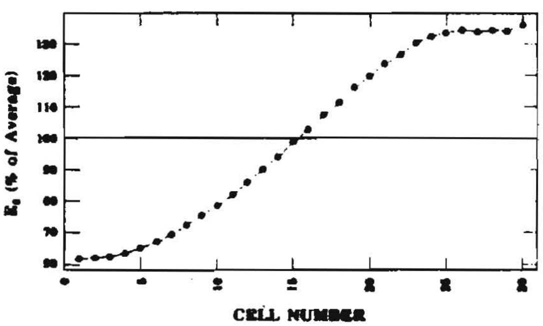

Fig. 3. Final measured field distribution in the RGDTL expressed as a percentage of the average measured value of E_0.

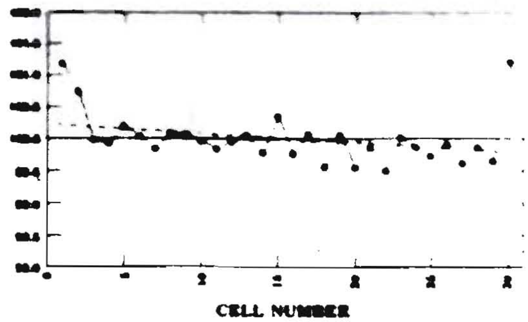

Fig. 4. Final measured RGDTL fields divided by the design fields.

Tilt Sensitivity and Field Stability

Tilt sensitivity measures a structure's field stability against tuning errors. In the DTL structure, resonant post couplers provide this stabilization when properly tuned. Tilt sensitivity measurements consist of two axial electric field measurements for different tuning perturbations in the cavity. A convenient way to detune a DTL cavity is to change the gap length in the two end cells. Figure 5 shows two field measurements and the corresponding tilt sensitivity for the RGDTL without post couplers. For the first measurement (top of Fig. 5), decreasing the cell-1 gap lowered the TM_{010} frequency 500 kHz. Increasing the cell-30 gap restored the frequency to 425.840 MHz, the same frequency as the unperturbed cavity. This type of detuning "tilts" the field toward cell 1. That is, it results in higher field in cell 1 and lower field in cell 30 with an approximately linear distribution in between. The second measurement (middle of Fig. 5) corresponds to opposite-sign perturbations of the end cells, which tend to tilt the field toward cell 30. Tilt sensitivity is the cell-by-cell difference between these two field measurements divided by the net perturbation applied to the end cells. Convenient units for tilt sensitivity are %/MHz.

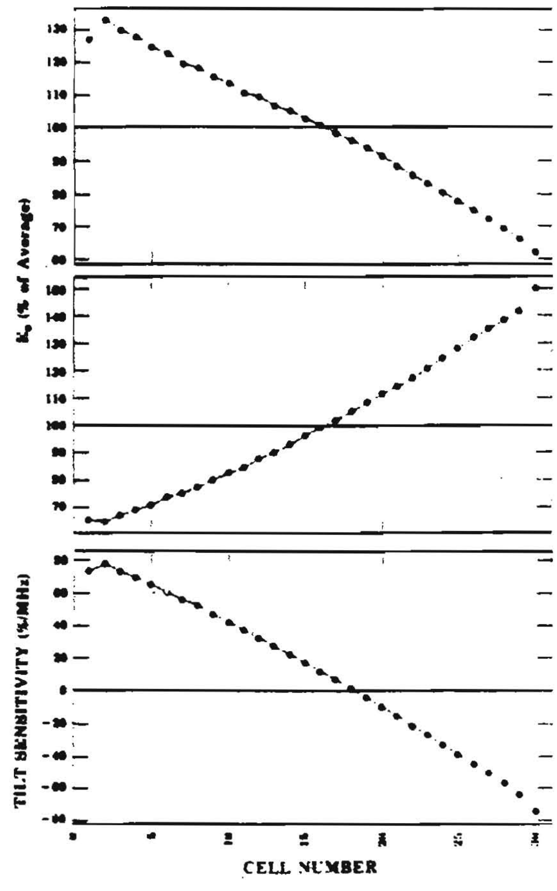

Fig. 5. Tilt sensitivity without post couplers (bottom) is the difference between a field measurement with a −100-kHz end-cell perturbation (top) and one with a +100-kHz end-cell perturbation (middle).

Neither of the field distributions in Fig. 5 resembles the post-coupler stabilized field of Fig. 3. In fact, the unperturbed field distribution without post couplers (not shown) has a slight end-to-end tilt of about 20% caused by the presence of the drift-tube stems. The RGDTL design ignored each stem's frequency effect on individual cells. The stem tends to raise the frequency because it lowers inductance by removing magnetic field volume from the cell. The effect is greater on the LE end where the cells are shorter. Thus, the cell frequencies are higher on the LE end than they are on the HE end. In a chain of coupled oscillators such as a DTL, this continuous detuning results in higher field in the lower-frequency cells at the HE end.

Post couplers couple capacitively to drift-tube voltages in adjacent cells. In the RGDTL, there are 14 post couplers alternating side to side, located at the longitudinal positions of the even-numbered drift tubes. If the effective coupling capacitances of the post coupler to the two cells are equal (corresponding to the post coupler positioned near the longitudinal center of a drift tube), and if the field levels in the two cells are equal (corresponding to equal and opposite voltage maxima on the ends of the drift tube), then the post coupler remains unexcited because the two adjacent cells drive equal and opposite rf currents onto the post coupler. A difference in field levels excites the resonant post coupler and results in rf power flow from the high-field cell to the low-field cell. Roughly speaking, the level of excitation adjusts itself to equalize the product of coupling times field level on both sides. Thus, the post coupler stabilizes the field distribution.

Post couplers in the RGDTL have a 30° bend ~5 cm from the end. Rotation about the (unbent) axis displaces the tip toward one end of the structure and hence increases capacitive coupling to one cell while decreasing coupling to the other. The stable field distribution for this configuration is ramped with lower field on the higher capacitance side. The post coupler is necessarily excited to maintain such a distribution unless fields without post couplers already incorporate the ramp, as discussed in Ref. 2.

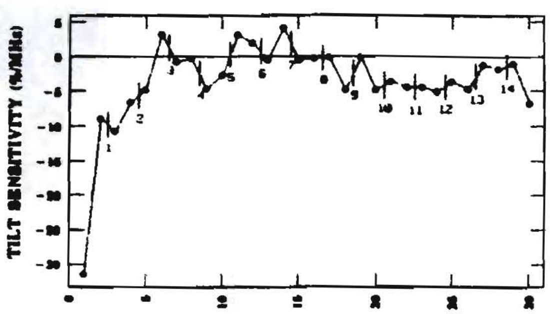

Fig. 6. Final tilt sensitivity measurement for the RGDTL.

Figure 6 shows the tilt sensitivity with post couplers measured for the field distribution of Fig. 3. Numbered markers show the locations of the 14 post couplers. With the exception of cells 1, 2, 3, 4, and 30, all the other cells' tilt sensitivity is below ±5%/MHz. We expect the tilt sensitivity parameter for the two end cells to be rather large: these two cells are severely detuned in order to make the measurement. Cells 2, 3, and 4 fall outside the ±5%/MHz limits achieved for the rest of the RGDTL. The local positive slope of the curve indicates that post couplers 1 and 2 are too high in frequency and should be lengthened for a lower (flatter) tilt sensitivity. Unfortunately, these two post couplers were already at the end of their travel. We decided not to make necessary modifications to insert them farther because the measured 10%/MHz tilt sensitivity in the low-field region on the LE end corresponds to about the same field error as 5%/MHz on the HE end where the fields are twice as high.

Table I shows the post-coupler penetrations and orientation angles for the field and tilt sensitivity of Figs. 3 and 6. Largest tip displacements toward the LE end occur in the region of the steepest ramp in the field between drift tubes 4 and 20. Final tuning involved angle adjustments as small as ±0.5° to achieve the desired field and penetration adjustments of about ±0.012 cm for minimum tilt sensitivity.

TABLE I: POST-COUPLER CONFIGURATION FOR THE RAMPED-GRADIENT DRIFT-TUBE LINAC

Post-Coupler Number	Drift-Tube Number	Penetration[a] (cm)	Orientation Angle[b] (degrees)	Tip Displacement[b] (cm)
1	2	15.494	1.0	0.02
2	4	15.494	49.0	1.92
3	6	14.971	42.0	1.70
4	8	14.717	37.0	1.53
5	10	14.666	47.5	1.87
6	12	14.638	40.0	1.63
7	14	14.610	32.0	1.35
8	16	14.557	42.0	1.70
9	18	14.618	32.0	1.35
10	20	14.488	32.0	1.35
11	22	14.531	23.0	0.99
12	24	14.656	19.5	0.85
13	26	14.666	3.0	0.13
14	28	14.660	2.0	0.09

[a]Indicates projection of the tip position from tank wall along the post-coupler rotation axis.
[b]Orientation angle indicates rotation about the axis of the post coupler normal to the tank wall, which results in displacement of the tip toward the low-energy end.

Conclusion

The RGDTL resonates at 425.000 MHz with the two slug tuners at one-third penetration. The axial electric field distribution is within ±0.5% of the design (+1.2% on the ends), and the fields change less than 5% for a 1-MHz end-cell tuning error. The RGDTL fields are ex-tremely stable because of the post couplers. We measured the axial field distribution for different amplitude and phase conditions at the two drive loops. With phase shifts as large as ±90° between equal amplitude drives, there were no changes in the relative field distribution larger than ±0.5%. Results were the same for mismatched amplitudes at the two drives and for different combinations of mismatched phase and amplitude.

References

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3. D. Liska et al.,"A High-Intensity Drift-Tube Linac with Ramped Accelerating Gradient," these proceedings.