EXPERIENCES WITH POST COUPLER STABILIZED STRUCTURES IN THE NAL LINAC

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ABSTRACT

The electrical characteristics of the first two linac cavities of the NAL linac that incorporate field-stabilizing devices have been determined. The measurements reported here include the stability of the electric-field amplitudes as well as detailed field and other rf measurements at low power.

I. Introduction

The electromagnetic fields of all cavities of the NAL linac except the first are stabilized by means of the post-coupler system developed at Los Alamos Scientific Laboratory.[1] At low intensity, the post couplers stabilize the fields against the effects of mechanical imperfections and perturbations. At high intensities, the post couplers act to stabilize the fields against the effect of beam loading.

The post couplers used in the NAL linac are copper rods approximately 20 in. long and 1 in. in diameter, with a flat eccentric tab 1 in. wide and 1-3/8 in. long, measured from the center of the post, on the inner end of the post. Each rod is positioned opposite the center of a drift tube. It can be moved in or out (total travel 2.5 in.) and rotated to change the position of the eccentric tab. Figure 1 is a view of a cavity with the end plate removed, showing the positions of the drift tubes and post couplers.

This paper discusses the NAL experimental work with the post couplers. Section II describes the experimental methods and Section III the results obtained to this time. All the results are restricted to low-intensity operation, because there has as yet been no attempt to operate the NAL linac at high intensity.

II. Methods

The accelerating fields were measured by the bead perturbation technique,[2] with high-speed digital data acquisition and processing. The equipment is an extension of that developed several years ago at MURA.[3] The computer used is the Linac Sigma-II

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Control Computer. With the program now in use at NAL, a complete run can be made, including computation at the tabular and graphic display of results, in approximately two minutes. This high speed is very important because many runs are necessary to stabilize and adjust the accelerating fields in a cavity.

For these measurements, the cavity being stabilized was made to resonate in the TM_{010} mode by means of a high-gain amplifier connected between a small pickup loop near the center of the cavity and the main drive loop of the cavity. The length of this feedback-loop line and the drive-loop penetration were very carefully adjusted to minimize reverse power to the cavity (VSWR $\approx$ 1.001, typically).

The post couplers were tuned (the fields stabilized) by the following method: The movable cylindrical tuners located near the ends of the cavity were first adjusted to their midrange position of 2-in. penetration. The fields were then measured and stored in the computer. Then the tuner at the low-energy end of the cavity was moved to its maximum penetration and the tuner at the high-energy end to its minimum penetration to produce opposite and approximately equal frequency perturbations at the ends of the cavity. The net effect of this perturbation is to produce a large tilt in the field (low field at the low-energy end and high field at the high-energy end) in a cavity without stabilized fields. The field stability was always determined by using this "standard" perturbation.

After the standard perturbation was introduced, the fields were again measured and the ratios of the normalized cell fields with and without the perturbation were computed. A graphic display of the ratios as ordinates versus axial positions as abscissae, an example of which is shown later in Fig. 5, is very useful in stabilizing fields. The post couplers were then moved in and out and the field ratios remeasured.

When the resonant frequencies associated with the post couplers are too low, that is, the posts too close to the drift tubes, the ratios of perturbed to unperturbed fields resemble the field ratios in an unstabilized cavity, an approximately straight line with a positive slope that depends on the frequency difference between the cavity TM_{010} mode and the associated post-coupler mode (see Fig. 5). If the post couplers are withdrawn past the point for proper tuning, the slope of the field ratios will first become negative and then sometimes highly irregular as the posts are further mistuned (see Fig. 6). When the posts are properly tuned, the ratios ideally are all exactly unity (the accelerating fields are not disturbed by the perturbations introduced).

In a perfectly built linac cavity with exactly periodic cells, one would expect the post couplers to be tuned properly when they were all the same distance from the drift tubes. In a real proton linac cavity with varying geometry, one might expect the drift-tube-to-post-coupler distance to increase slightly with energy because the associated capacitance increases slightly with increasing drift-tube length. Usually we have found that to be the case, although construction and assembly errors have made the effect nebulous in some instances.

It must be emphasized that, after the posts have been tuned, the fields are stable but the configuration of the fields is not necessarily that of a "flat" field. Figure 7 is an example. With the eccentric tabs on the ends of the post couplers, it is possible to remove all but very short (one or two cells) field errors. Turning an eccentric tab toward one cell and away from the adjacent cell will reduce the field in the first cell and increase that in the second cell. Thus, the effect of rotating a post is to introduce into the field a step that is centered at the post. These step effects are cumulative, so that if, for example, all the posts are rotated 90° from the neutral position for maximum effect, very large field tilts will be introduced from end to end in the cavity.

In some cases, when the posts must be rotated 90° to flatten the cavity fields, the post frequency is changed enough to require retuning in order to maintain the desired stability. The stability is continually measured during the field-adjustment process and the retuning can easily be carried out simultaneously with the adjustment of the fields.

Since the post-coupler position affects the resonant frequency of the cavity, the movable cylindrical tuners must be used to adjust the TM_{010} frequency to within about 1 kHz of the design frequency before the measurements are finished. The uncertainty in the frequency is caused mainly by variations in the dielectric constant of the air in the cavity at the time the measurements were made. The final frequency adjustments are made under vacuum conditions with temperature control and a single automatic movable tuner.

The effect of the single movable tuner on the normalized field distribution was measured to be approximately ±1 to 2% peak throughout its entire range. It functions almost entirely to compensate for short-term temperature variations after a rapid, large change in heat load (rf system turned on or quadrupoles turned on or off). It therefore stays in the same position nearly all the time and thus has negligible effect on the fields.

III. Results

Operation of the system can best be illustrated by means of the displays generated through the linac control computer. Figure 2 shows the parameter display of the program. Parameters of the bead perturbation, integration of the fields, and the display of results are given. The values can be changed by moving a cursor to the number and varying it either with the linac control knob or by typing in a new value. Hard copies of this parameter display or any of the succeeding figures can be produced as desired from the oscilloscope displays by an integrated copying machine.

Figure 3 is a plot of raw data. Here frequency is plotted versus distance through the cavity. The lower plot gives part of the same results in expanded scale. Next, Fig. 4 is a plot of unperturbed fields with the post couplers somewhat mistuned. Figure 5 is then the ratio of perturbed to unperturbed fields for this post-coupler configuration. The overall positive slope of the "curve" shows that the resonant frequencies of the post couplers are too low. In Fig. 6, the post-coupler resonant frequencies are too high.

Figure 7 is then a plot of unperturbed fields in which the post couplers have been moved so that the fields are stabilized, but not adjusted for flatness. The tabs are then rotated and Fig. 8 shows unperturbed fields that are both stabilized and adjusted. The difference in vertical scale between Figs. 7 and 8 should be noted. Several runs are shown in Fig. 8 as an indication of the small scatter of the results.

Finally, Fig. 9 is a plot of the final ratios of the stabilized and adjusted fields, to show that the ratio of perturbed to unperturbed field indeed converges to unity to within less than 0.5%.

We have not yet had time to investigate some of the other interesting properties of post couplers, such as the role they have in reducing phase variations within the individual cavities under conditions of very heavy beam loading. It may be remarked that we have as yet observed no deleterious effects of the post couplers.

IV. Acknowledgments

It is a pleasure to acknowledge many illuminating discussions of post couplers with D. A. Swenson and E. J. Schneider of LASL. We also give our thanks to our NAL colleagues, particularly to R. W. Goodwin, who wrote the elegant and flexible computer program used in this work, and to D. E. Young, who has aided and encouraged us throughout the entire effort. All people in the field owe a significant debt to the pioneering work of S. Giordano on field stabilization.

References

[1] D. A. Swenson et al., Proc. of the VIth International Conference on High Energy Accelerators, CEAL-2000, Cambridge, Mass., 1967, p. 167.

[2] J. C. Sluter, Microwave Electronics (D. Van Nostrand Company, Inc., Princeton, N.J., 1950), pp. 81-83.

[3] C. W. Owen et al., Proc. of the 1966 Linear Accelerator Conference, LA3609, Los Alamos, New Mexico, p. 140.

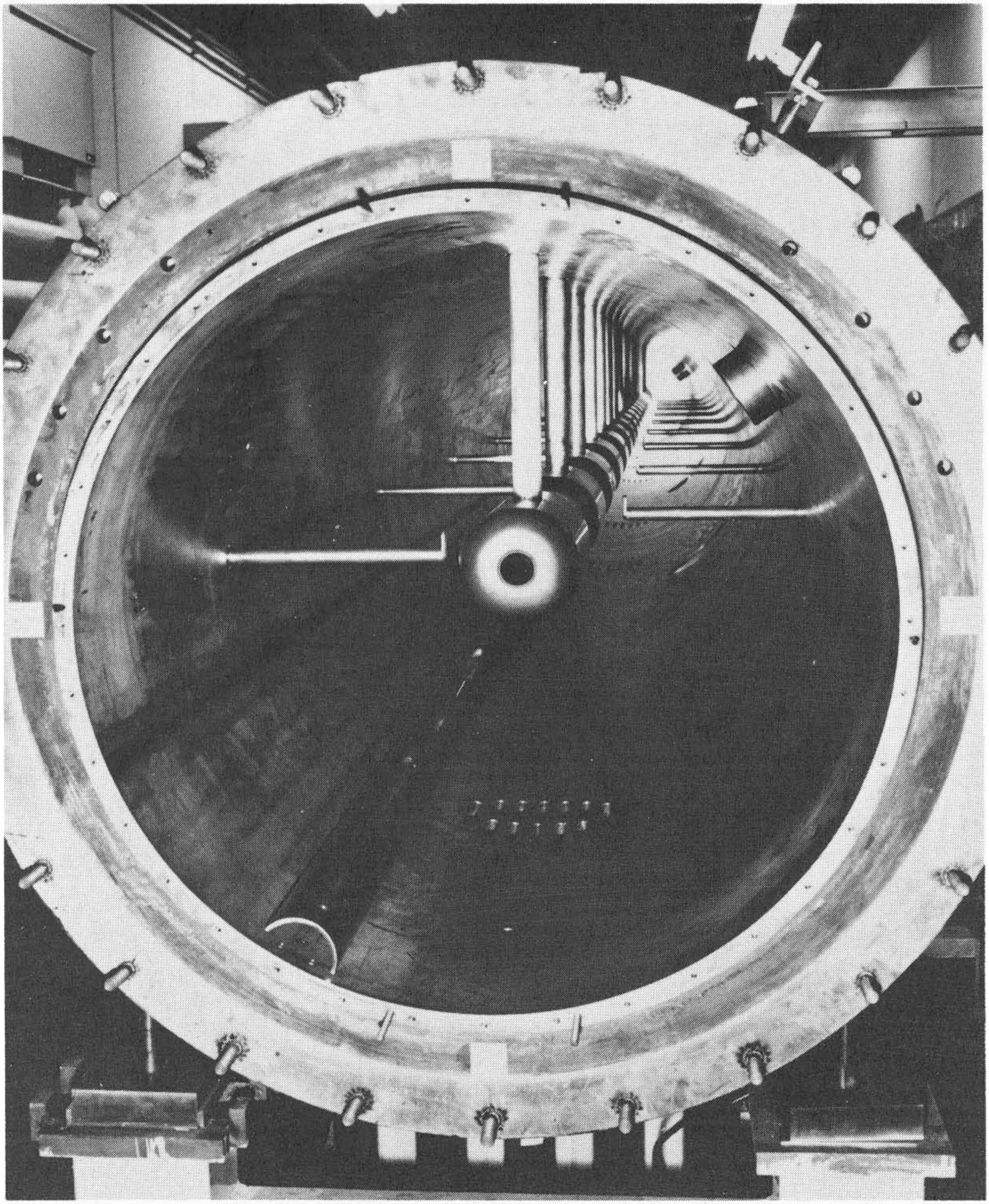

Fig. 1. End view of a cavity, with drift tubes and post couplers visible.

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   CAVITY FIELD MEASUREMENT
 TANK NUMBER........*PRINT.. 4
 LEAD-IN DISTANCE........... 50     MM
 EXIT DISTANCE.............. 25     MM
 DISPLAY MAX FREQ........... 2000   HZ
 LOWER DISPLAY START........ 15000  MM
               RANGE........ 2000   MM
 FREQ LIMIT -UPPER.......... 2000   HZ
            -LOWER.......... 1000   HZ
 INTEGRATION TRIM DISTANCE.. 0      MM
 STEP SIZE.................. 2      MM
 BASE POINT WINDOW.......... 2      STDEV
 INCLUDE T FACTOR   1=YES... 0
 NORM FIELD DISP HALF WIDTH  5      %
 CELL GROUP SIZE             4

*WRITE RUN  N= 550  *READ N= 546

*START RUN..........*DISPLAY
*CALCULATE AND PRINT FIELDS.
*DISPLAY FIELDS............. 6
*AVERAGE THIS RUN........... 3
*PRINT AVERAGES.............
*MOVE RUN X TO RUN Y     XY= 15
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Fig. 2. Alphanumeric parameter display used in the field-stabilization method

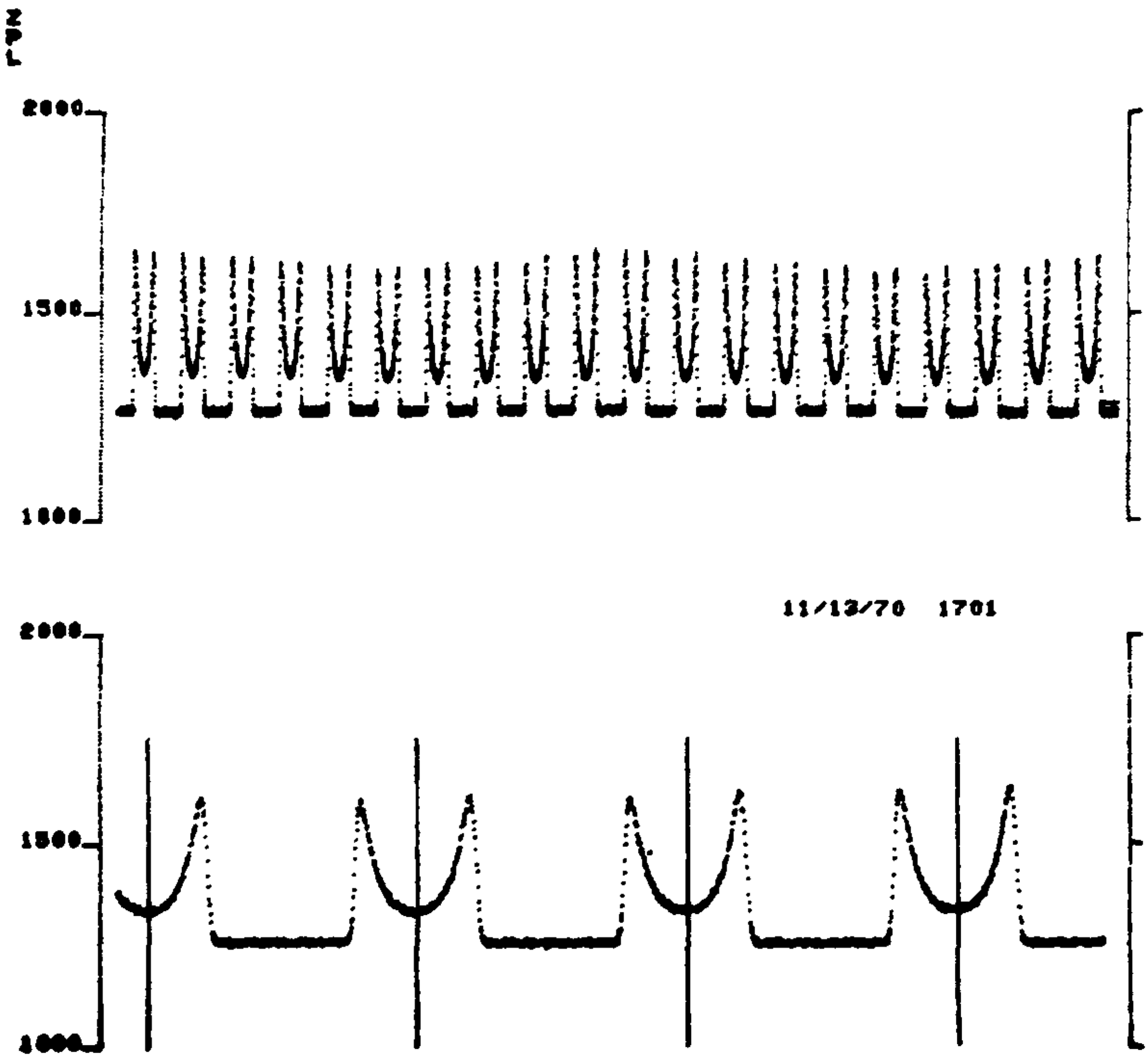

Fig. 3. Frequency vs distance through a cavity.

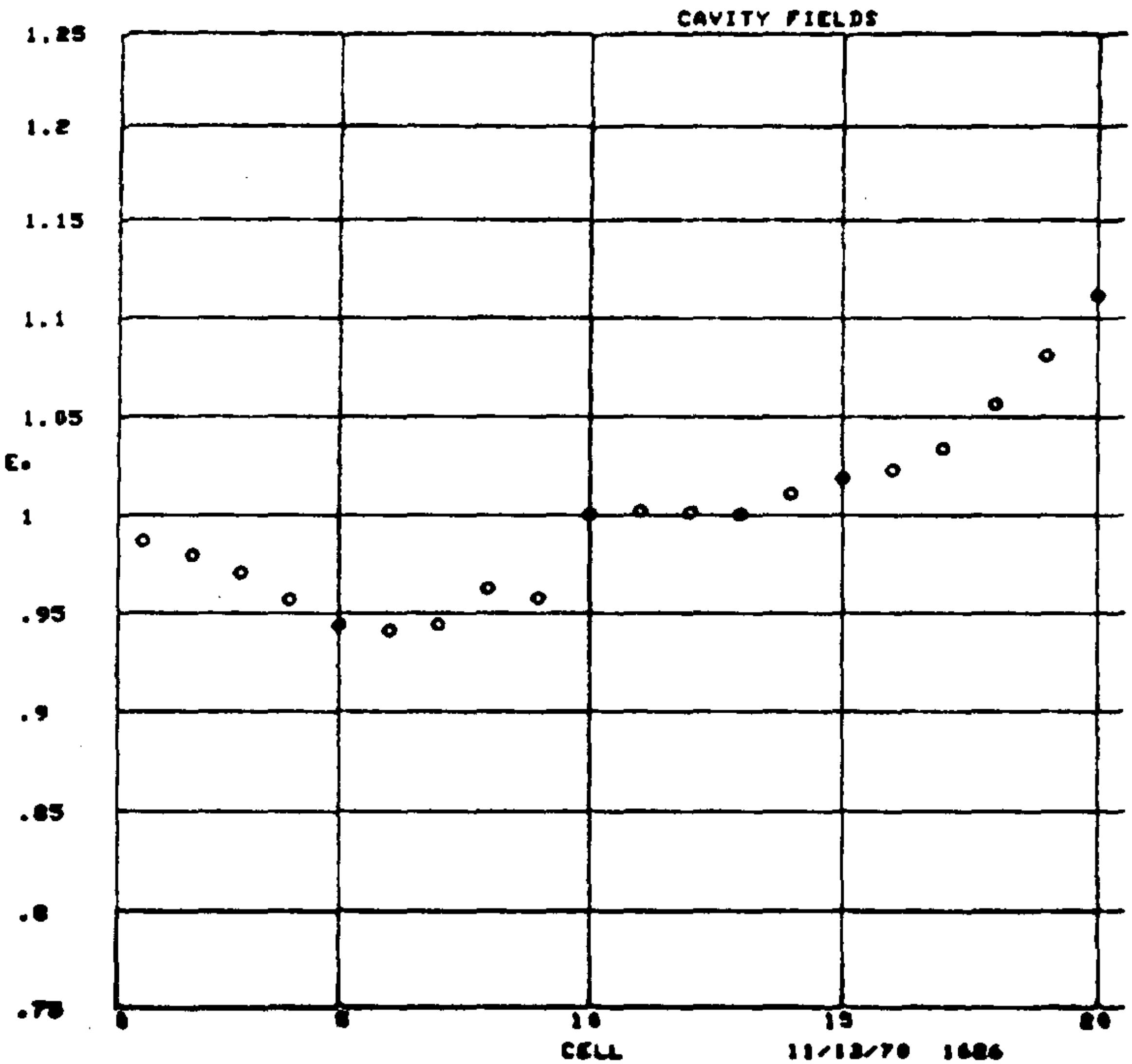

Fig. 4. Unperturbed fields with post couplers mistuned.

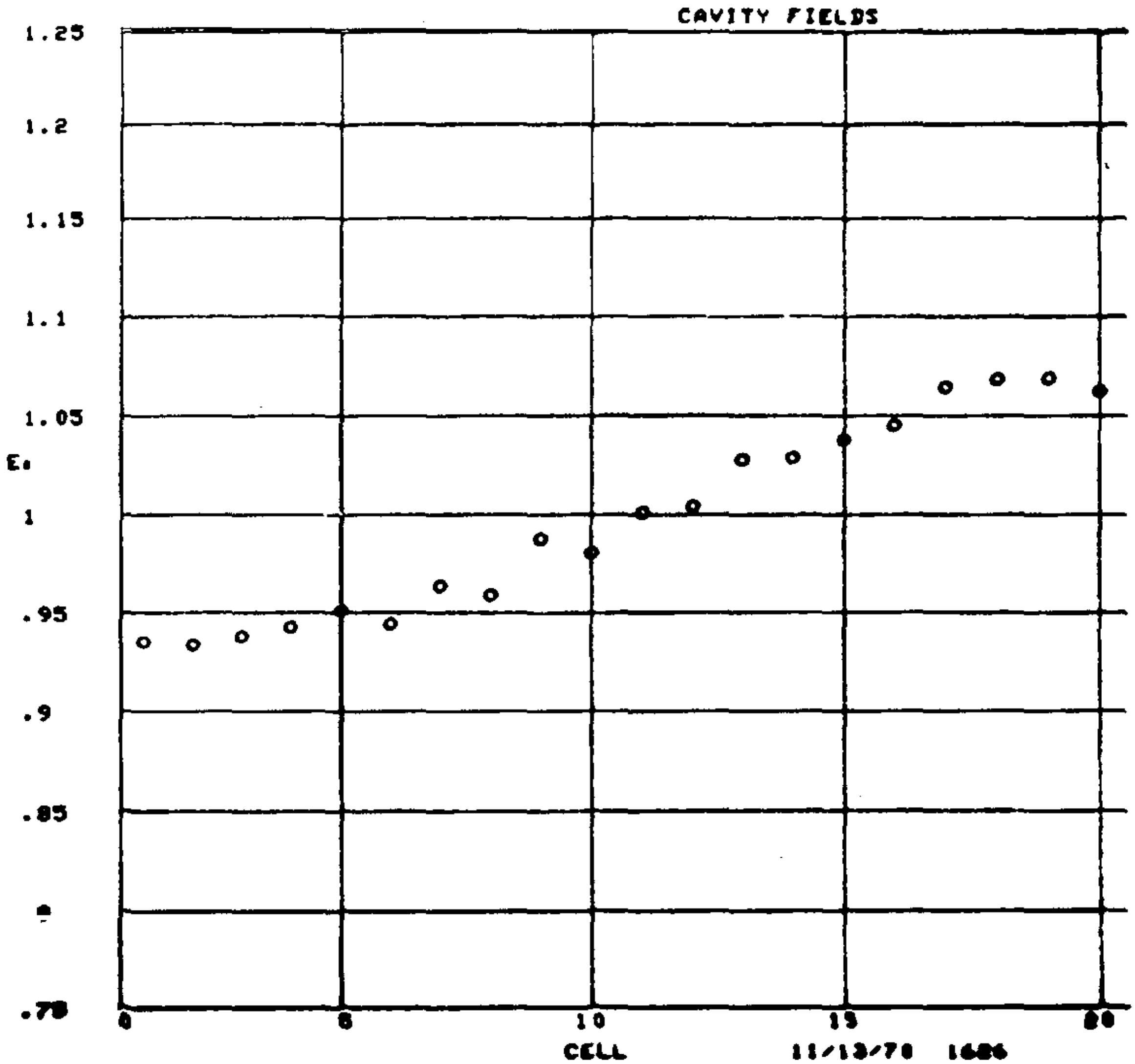

Fig. 5. Ratios of perturbed to unperturbed fields as in Fig. 4 (post-coupler frequencies too low).

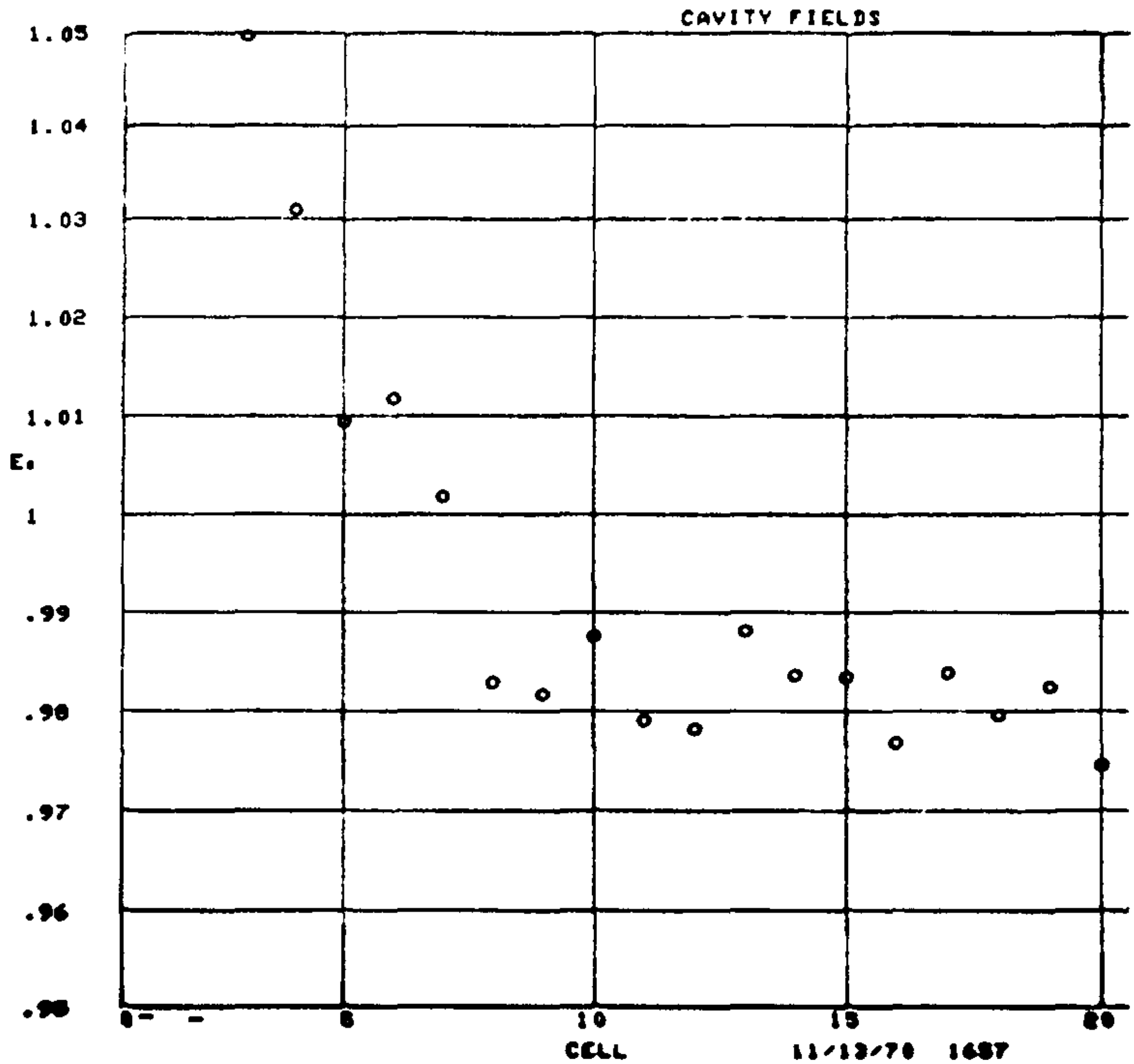

Fig. 6. Field ratios (post-coupler frequencies too high).

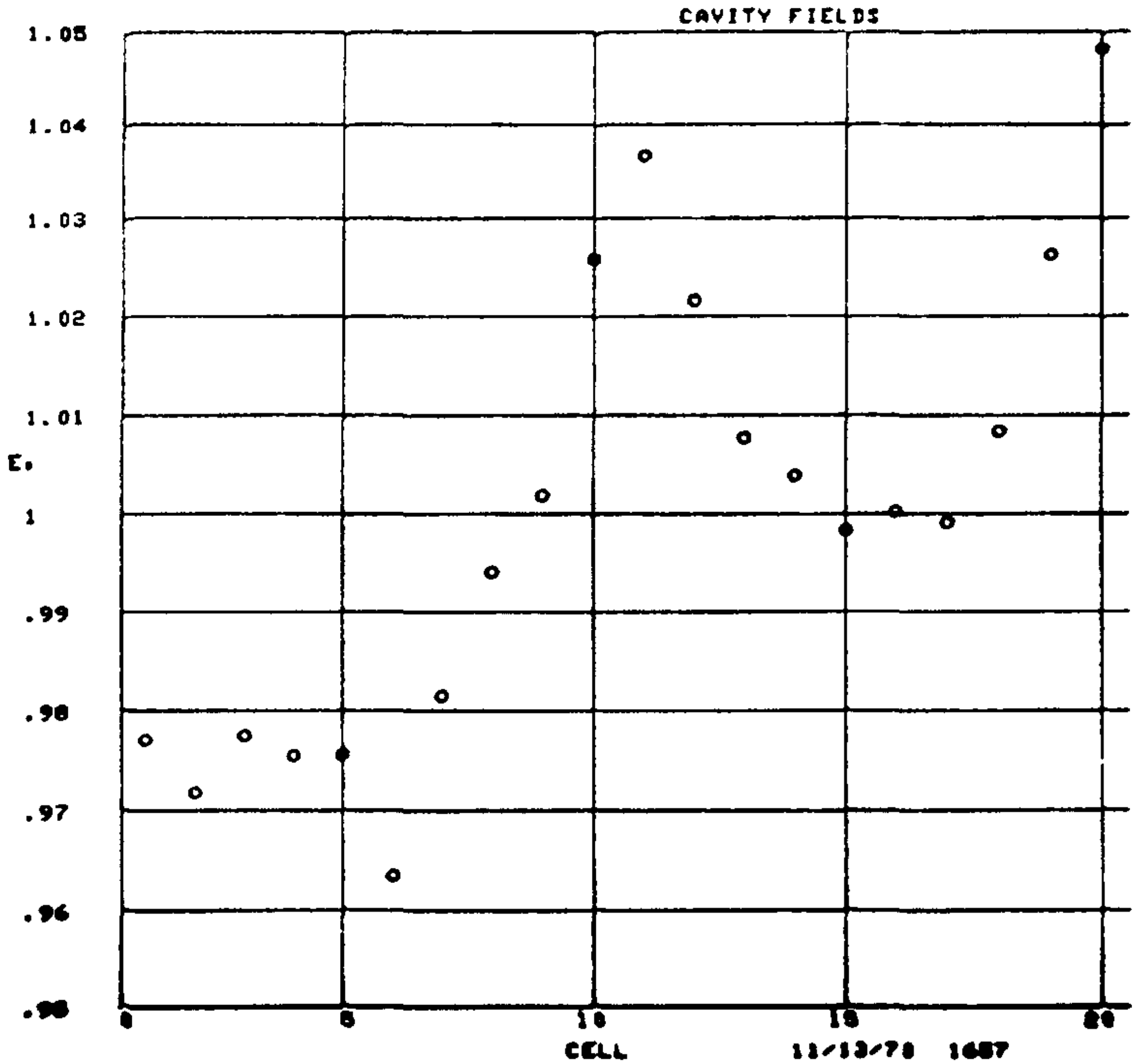

Fig. 7. Unperturbed fields--stabilized but not flattened.

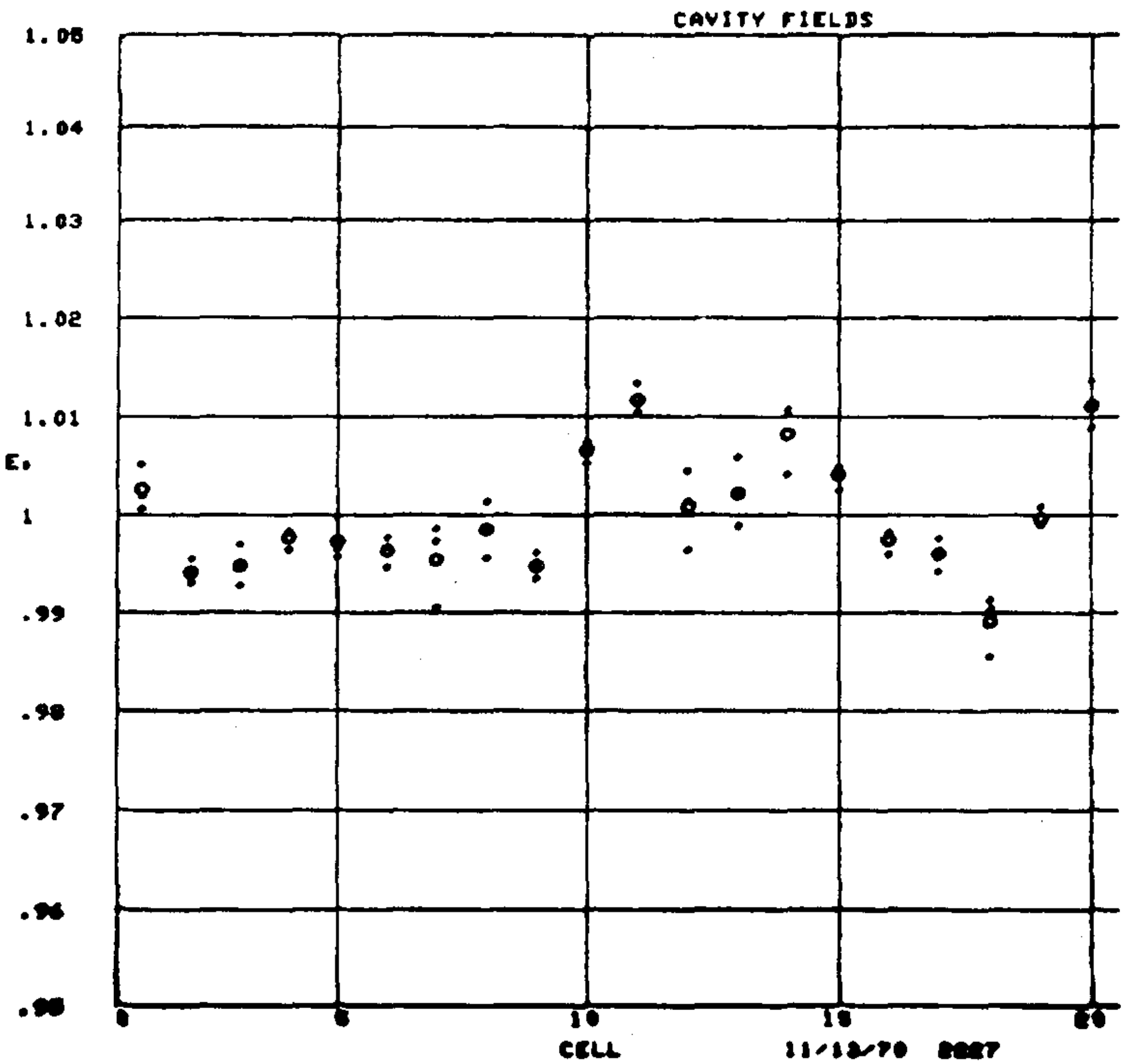

Fig. 8. Stabilized and flattened fields.

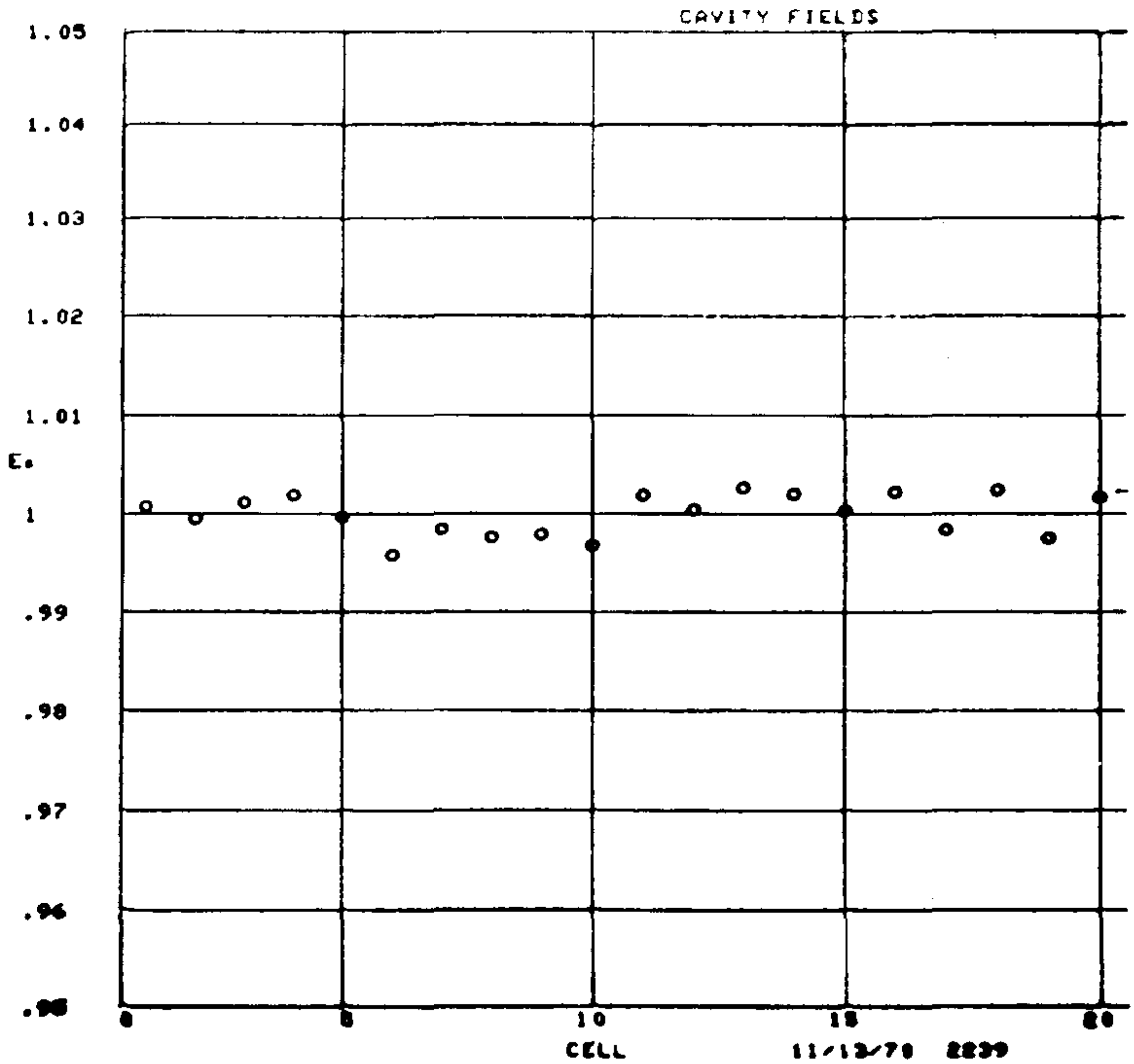

Fig. 9. Final ratio of perturbed to unperturbed fields.

DISCUSSION

M. Promé (Saclay): Have you found it useful to set the tuners individually or do you adjust them by always moving them together?

C. W. Owen (NAL): It doesn't really matter. This stabilization system does actually work quite well; we have found for starting out the initial tuning you can get your gross tuning done quite easily simply by looking at changes in the H field at the wall. After that, though we have deliberately introduced perturbations as large as is possible to do by putting all of our subtuners at one end at one stop and all the others all the way the other way, we do not see significant variations in the field. You can make them quite stable so essentially you can go in and move your tuners at will without worrying about the field changing.

T. Nishikawa (University of Tokyo): Is there any problem with discharges between post couplers and drift tubes?

C. W. Owen: No, none whatsoever. Our linac runs at 2.6 MV/m nominal field, and we run them considerably higher than that.

D. Swenson (LASL): We have done no work with post couplers for about two years, since we were doing our model studies, and we will be putting post couplers in tank 3 in a month or so (first work we have done since our model work). Now we fully intend to adjust the post couplers so that the gap between the end of the post coupler and the drift tube is tapered. It is my understanding that on tank 2 you left the gap between the end of the post and the drift tube be constant for the whole tank. My question is on these later tanks did you do the same thing?

C. W. Owen: We did in some cases. We also tried tapering them; except in one case, we haven't ended up with the strictly tapered gap. Under ideal conditions I doubt very much if you could tell the difference between a tapered gap and a stepped one in any sort of reasonable size. In some cases, our gaps have not been monotonically increasing as you go toward the high-energy end. The gap I am talking about is the gap between the end of the post coupler and the drift tube itself.

R. H. Miller (SLAC): Why would one taper them? Is it because of the taper in the tank?

C. W. Owen: No. The tank is not tapered. The capacitance between the end of the post coupler and the drift tube increases as the drift-tube size increases, at least up to a point, and you would expect it to be a smooth variation. I didn't show any cases up here in which we have an overcompensated structure, that is the perturbation produces really strange looking things going the opposite way from what you would expect. These effects, in all cases, do happen at the low-energy ends first, that is, with the shorter drift tubes. I think the smoothness of the taper simply implies a smooth variation along with it. We haven't seen that it makes much difference.