RF PERTURBATION MEASUREMENTS IN LONG LINAC CAVITIES*

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Summary

Equipment and procedures have been developed for measuring the axial accelerating electric field in proton linear accelerator cavities. The method used is the usual one of measuring the change in resonant frequency caused by a small perturbing sphere on the axis of the cavity. The frequency change is determined at millimeter intervals along the axis by measuring the corresponding period length using an on-line digital computer. The computation is carried out on the computer so that the derived fields can be obtained, integrated, plotted, and compared. The method is rapid and the increased precision of the measurement allows better knowledge of the fields in operating linear accelerators. This equipment has been used on the 50-MeV linac injector for the Zero Gradient Synchrotron at Argonne National Laboratory.[1] It has also been used to measure the axial field in a cavity with fields which can be calculated using a field computational program.[2] The measured and calculated field values have been compared.

Description of the Equipment

The equipment is shown in Fig. 1. The perturbing bead is pulled along the axis of the cavity on a silk suture thread tightly stretched at constant tension. Ramps placed in a few of the drift tube bore holes insure that the bead remains nearly on the linac axis so that the error from the sag in the thread will be negligible. The thread is driven by a variable speed motor to allow the bead to move through one linac cell in about one second. Readings of the cavity frequency are taken each millimeter along the axis as determined by the string-driven position marker which is a low inertia toothed wheel interrupting a light beam to a photo diode.

The linac cavity is self-excited by feeding back the signal from a pickup loop close to one end of the cavity through the main power amplifier to the normal cavity drive loop. The signal from another pickup loop is amplified and mixed with the appropriate harmonic of a very stable crystal-controlled 10 MHz oscillator to give a difference frequency of about 1 kHz. This difference frequency is used to generate well-defined period markers at the positive zero-crossing points. These are sent through a gate which is opened by a shaped pulse from the string-driven position marker. The first period marker through this gate then opens a second gate which couples the signal from a 10 MHz oscillator to a binary scaler. The end of one, two, four, or eight periods is signaled by the appropriate period marker, which closes both gates and thus terminates the 10 MHz signal to the scaler. The scaler output thus provides an accurate period measurement of the difference frequency, at millimeter intervals along the linac cavity, in computer compatible form.

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

Calculations and Corrections

The periods are converted to frequencies by the computer. The perturbation in the frequency is obtained by subtracting the frequencies determined when the bead is in the gap field from an unperturbed average frequency obtained during the transit of the bead through the drift tube. The field, E_i, at each millimeter position can then be computed from the usual perturbation formula (for a metal sphere in the absence of magnetic field):[3]

$$\frac{\delta f_i}{f_i} = \frac{k\,\delta V}{W}\,\epsilon_o E_i^2$$

where k is a constant close to 3/4, δV is the volume of the perturbing sphere, W is the stored energy in the cavity, and ϵ_o the free space dielectric constant. Except for the constant factor, the E_i values in the gap are the square roots of the frequency perturbation δf_i. These can be plotted to give the field shape throughout the gap. The normalized integral of the E_i over the unit cell is a measure of the average accelerating field. The transit time factor can also be calculated from the measured field values.

The measurement of the field becomes difficult when the field becomes very small, as it does beyond about one drift tube bore hole radius into the bore hole. In order to obtain useful values for the average accelerating field and the transit time factor, it is necessary to apply a small correction factor to the calculation of these quantities. The correction factors were obtained from the fields calculated in a field computational program.[2]

Considerable time was spent during the development of this equipment in evaluating the errors caused by using relatively large perturbing beads. One ball-size correction arises because of the approximation of treating the field as uniform over the ball volume, δV, so that the frequency shift is just the simple ratio of $E_i^2 \delta V/W$. If the field is not uniform over the ball volume (or if image effects are appreciable), the simple formula is not strictly valid. The correction may be determined by using successively smaller balls in the same field and hopefully extrapolating to zero ball size. The correction will be greatest where the fields have the highest gradients and where the balls are closest to the drift tube surfaces, which in this case is in the early linac gaps. Figure 5 shows the fields, in a cavity whose dimensions are shown in Fig. 3, measured with three different ball sizes, i.e., 1/8, 3/16, and 1/4-in. diameters. No ball size correction is apparent over the region of the geometric gap and in the bore hole the accuracy of the measurement is not sufficient to determine the correction.

Another correction depending on ball size is relevant to long cavities. It is recognized that if the frequency of a single cell which is strongly coupled to many cells in a long linac cavity is perturbed as, for example, is the case when the end wall of a cavity is deflected, a change of amplitude of the field along the tank will result.[4] By virtue of the same effect, the change in frequency of the cell caused by the perturbing ball will result in a change in the field for a long linac. In the case of a 3/8-in. ball in a 110-ft. cavity, the ball itself induces a "tilt" in the field of a few percent and a correction must be made for this effect.

Results

The equipment and procedures have been checked out on a three-foot, 10 drift tube cavity shown in Fig. 2. The drift tubes are of the Christofilos type and this cavity represents the low energy end of the present operating linac at ANL. These fields have been measured and the transit time factors calculated from the data. The experimentally measured values differed from the values used in the design to obtain the drift tube spacing from about 10 percent to 5 percent. This means that the field must be increased in these gaps by about this amount if the linac acceptance is to agree with the design value.

Figure 3 shows a 1.8-MeV unit cell of the type contemplated in the present linac designs. In this cavity the fields are calculable using the present mesh-type field computational programs.[2] The perturbing ball is pulled vertically along the axis with tension provided by a constant-tension device mounted in the lower drift tube. In this ideal case, many runs can be taken so that very accurate average values can be obtained in order to make comparisons with the computed values. This comparison of the measured and computed field is a subject which is important in view of the extensive use of the computational programs for the new linacs at LASL and BNL.

Figure 4 shows the comparison of the measured and the computed fields for the cavity shown in Fig. 3. The computed field is the solid line; the experimental values are shown in the plotted points. The estimated experimental errors are shown on several points and are only significant where the fields become small inside the bore hole. A departure is clearly indicated, and it is believed that this difference is caused mainly by inaccuracies in the field computational program. The average accelerating field calculated from the measured field is 3 percent smaller than the value obtained from the computed field. The value of the transit time factor for the measured field is 3 percent higher than the value obtained from the computed field. These errors may be indicative of the expected accuracy of the MESSYMESH Program[2] for calculating these values in this extreme geometry. Where the gaps are longer, the error will probably be smaller.

Conclusion

This equipment has proven useful in making accurate measurements in existing linacs and in providing a more accurate determination of the fields in geometries which can be computed than has heretofore been possible. Thus it allows the accuracy of the mesh-type field computational programs to be determined. It is felt that this equipment will make possible more nearly exact design and better performance of all linacs in the future.

References

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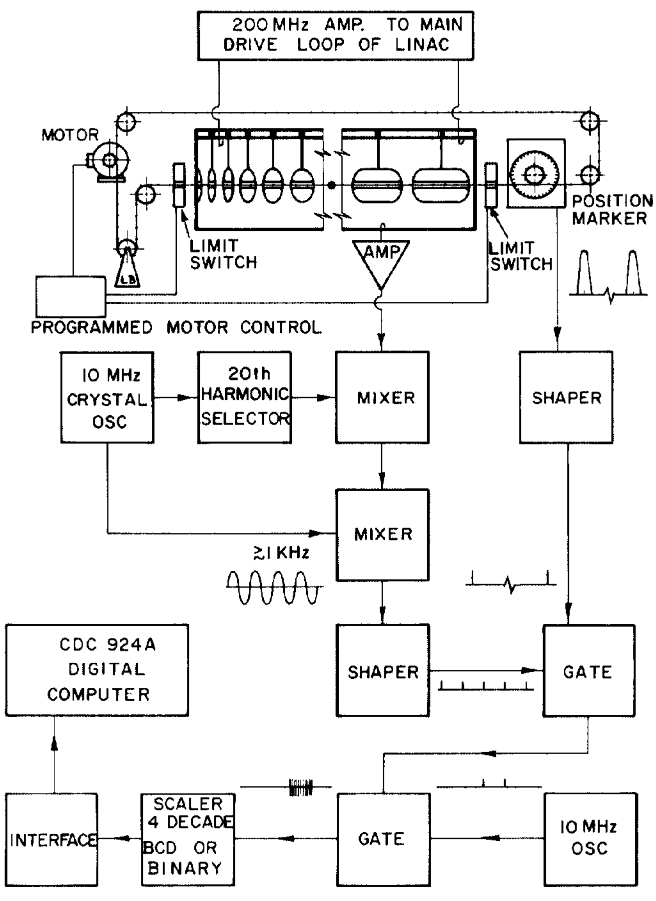

Fig. 1. Block diagram of the equipment used to measure the linac fields of perturbation techniques.

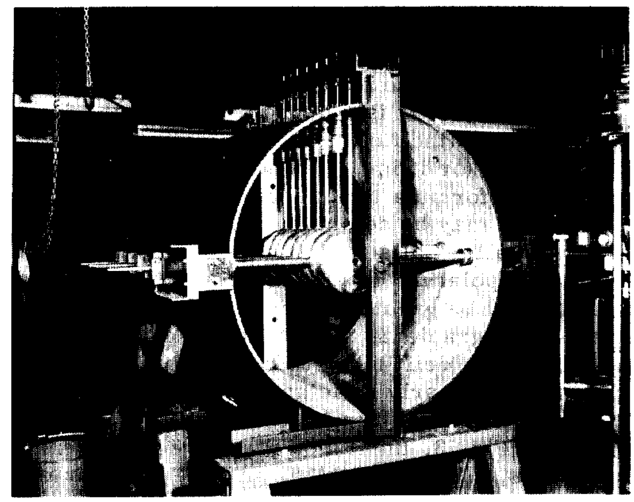

Fig. 2. Ten drift tube test cavity (with end plates removed).

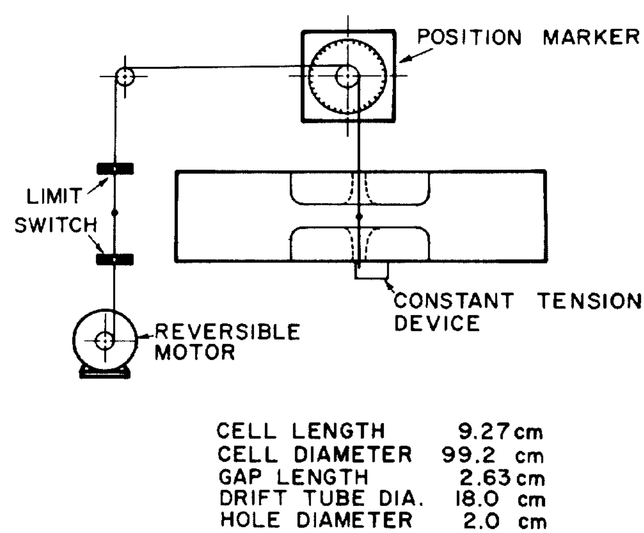

Fig. 3. Field measurement in a 1.8-MeV unit cell.

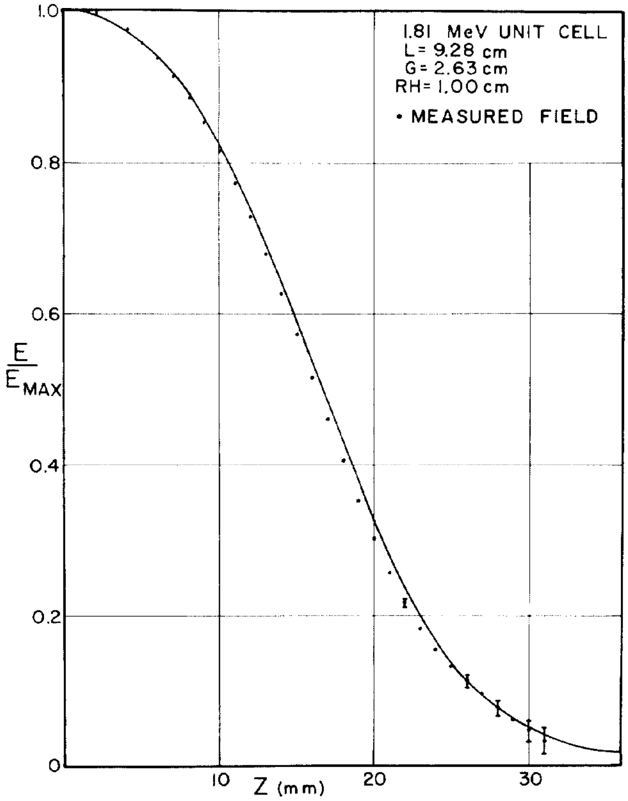

Fig. 4. Comparison of the measured and computed field in the 1.8-MeV unit cell.

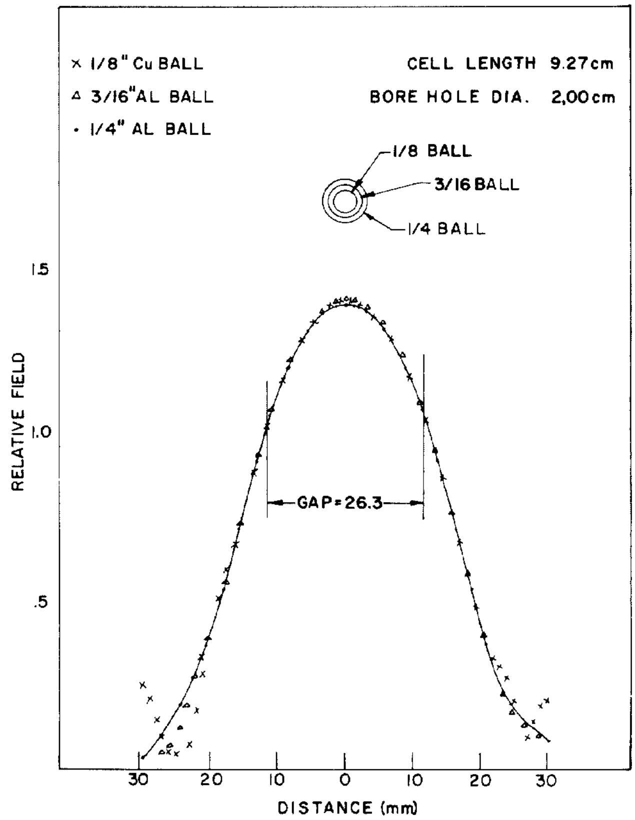

Fig. 5. Field distribution in the 1.8 MeV unit cell as measured with three different ball sizes.