J. Walters (Brookhaven National Laboratory)

Linac Tank Flattening and Subdivision

To facilitate axial field flattening, the BNL Linac has 56 ball tuners. These are movable over a range of 3 inches and consist of solid copper spheres varying in diameter from 5 to 6 inches, depending on location. The tuning capability derived from this is 200 kc/s, at a nominal frequency of 200 mc/s.

Field measurement is accomplished with a series of 12 probes, each probe was calibrated against a master probe in a tank model section.

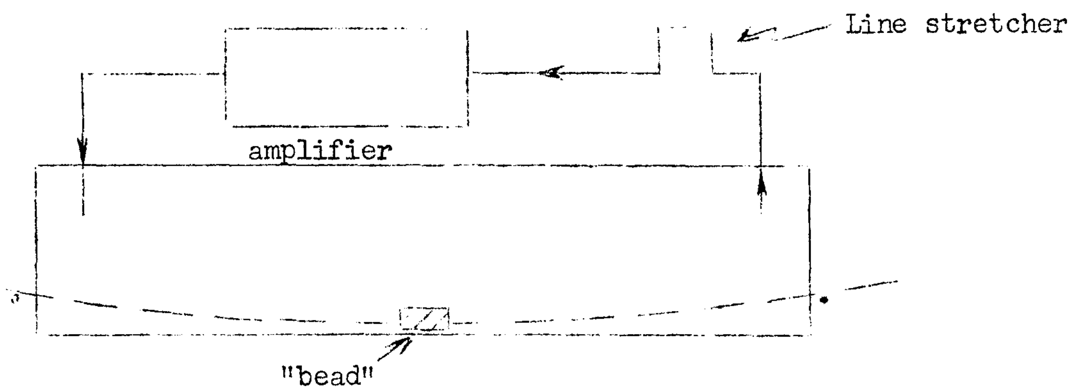
Prior to Linac assembly each of the 11 sections was measured individually and frequency was plotted as a function of ball tuner settings, moving all the ball tuners in unison. A typical frequency variation is 50kc/s per 3/4 inch of movement of the whole block of ball tuners. These individual tank curves were very helpful later in setting the resonant frequency for the whole linac at 201 mc/s.

Initially the fields were flattened with the probe pick-up values and a beam of output energy of 50 Mev was observed. Thereafter the beam intensity was gradually improved with further adjustment of the ball tuners. However, it was then found that the output energy had deteriorated to 35 Mev as measured with a magnetic analyser.

It was then decided to open the Linac tank and to use a "bead pulling" method for field flattening. This method makes use of a "bead" (copper cylinder, 12" long, 1 $\frac{1}{4}$" diameter) which is introduced into the tank and rests on the inside wall, acting as a perturbation. Regions of high axial fields in the Linac are found by pulling this bead through the Linac (with fish lines) and observing where the largest shifts in resonant frequency occur

$$\Delta f \propto H_{\phi}^{2} \propto E_{z}^{2}$$

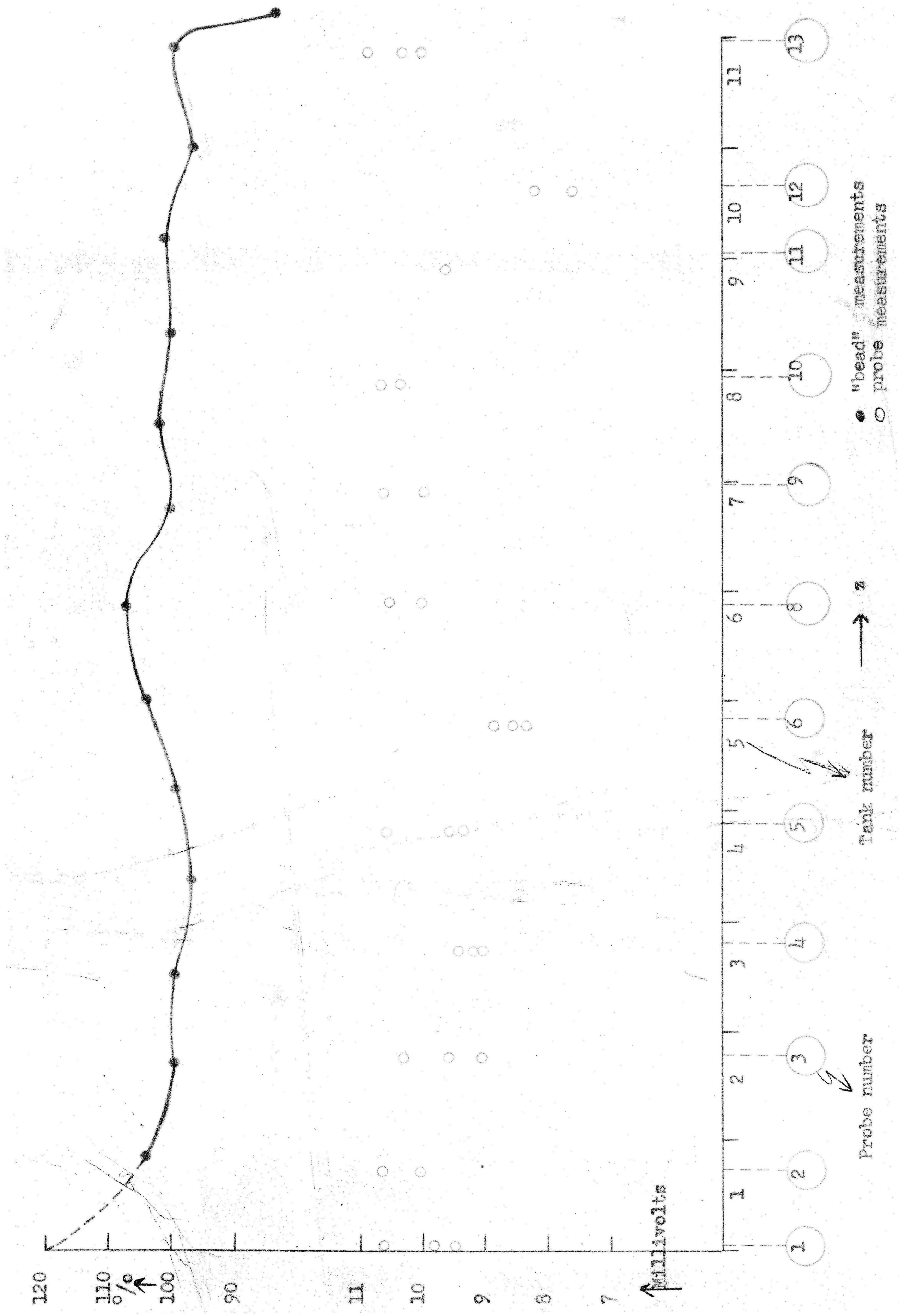
It is necessary in this type of measurement that the Linac be used as part of a self excited loop, so that it independently can find its resonent frequency. The diagram below illustrates this method:



It is obvious that the "bead" pulling method can only be done when the Linac tank is open to the atmosphere. Under normal conditions of an evacuated tank it is possible, however, to use each individual ball tuner in succession as a local perturbation, again running the Linac self-excited. The results are analogous.

After the Linac tanks were flattened with the "bead" method a particle beam of 50 Mev was obtained.

From all this it became clear that, possibly due to local mechanical variations in the vicinity of the probe mounts, some of the probe calibrations were in error. A typical probe pattern is shown on the next page.



120
110
%
100
90
11
10
9
8
7
Millivolts
1 2 3 4 5 6 7 8 9 10 11
1 2 3 4 5 6 8 9 10 11 12 13
Probe number
Tank number
z
● "bead" measurements
○ probe measurements

The following empirical rules have been found useful in obtaining tank flatness.

a) The Linac has movable end plate sections; this is to compensate for possible flexing of the whole end plate. The movable section at the low energy end especially has the pronounced effect of tilting the field distribution up or down.

b) Changes in the waveguides connected with the tank may result in a lower resonant frequency of the combination of guides and cavity, with consequent change in field flatness. Therefore additional tuning in the waveguides has proved to be helpful.

c) The application of the Berkeley (LRL) method.*

Writing E_z as

$$E_z = E_o \, J_o \, (k\, r) \, e^{\, i\omega t} \left[1 + \sum_{n=1}^{\infty} e_n \cos\left(\frac{n\pi z}{L}\right) \right]$$

and radius as

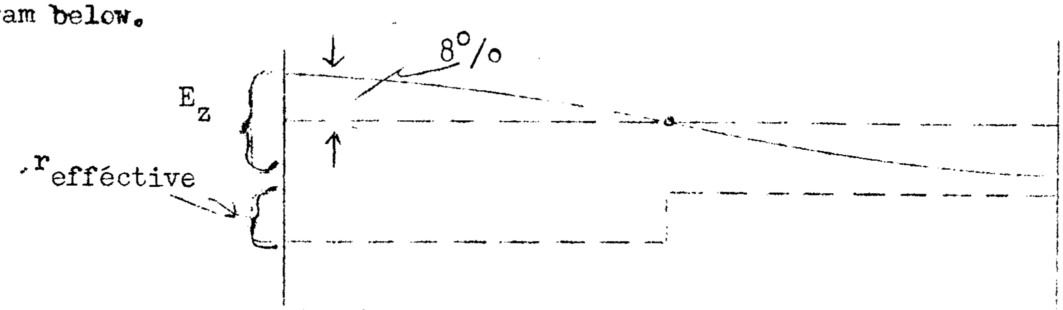
$$r\,(z) = r_o \left[1 + \sum_{n=1}^{\infty} P_n \cos\left(\frac{n\pi z}{L}\right) \right]$$

Then it can be shown that

$$e_n = \frac{8\, N^2}{n^2} P_n$$

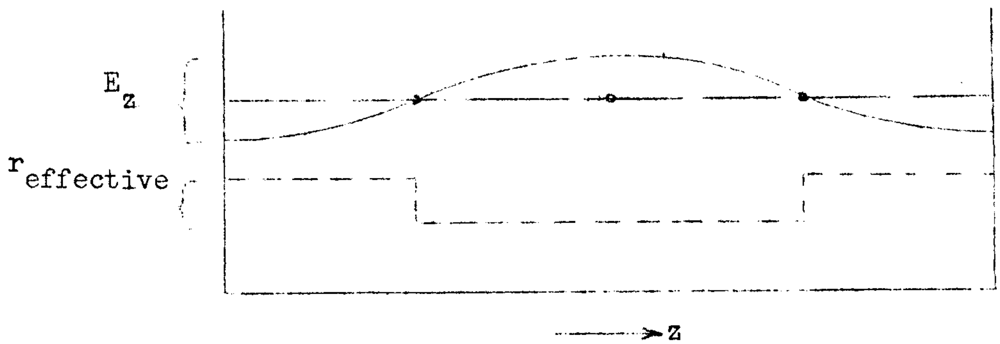
In case of the BNL linac $N = \frac{L}{\lambda} = 22.2$

From this, for example, an 8°/o 1st harmonic variation can be corrected by tuning the two halves of the tank differently by 4 kc/s, as illustrated in the diagram below.



* BST 26. III. 1955

An 8°/o second harmonic variation would be corrected by 16 $kc/_s$ as shown below.



To get an impression of mechanical tolerances involved consider that the 8°/o 1st harmonic variation represents a radius variation of 22 ppm and ball tuner variations (in unison) of 0.075 inches. These figures are inversely proportional with L^2 (L = linac length). Therefore a longer Linac will require greater mechanical stability.

In a first approach, however, the length of the Linac will be limited by mode separation. In the case of the BNL Linac this is calculated to be

$f_n - f = 56\ n^2\ kc/_s$ (for an equivalent empty cavity)

From this:

n =	1	2	3	
fn - f =	56	224	504	
$(fn - f)_{exp.}$	?	122	417	excitation by signal generator
$(fn - f)_{exp.}$	30	65	?	from position of nulls and frequency of ripple on the waveshape of Linac probes.

The last column was obtained by observing higher frequency modulations on the rf waveshape. The fact that these are present means that higher modes are being excited to a certain extent. By determining now the null positions and frequency of the ripple the numbers in the last column were deduced. The smaller separation values obtained indicate that the mode separation might be smaller than that given by

$$(f_n - f_o) = \left(\frac{cn}{2L}\right)^2 \frac{1}{2f_o}$$

Having obtained tank flatness at approximately the proper resonant frequency the rf frequency fed in was intentionally shifted and probe readings were taken. From the results it was found that a frequency shift resulted in a "curved" field distribution. This is illustrated in the diagram on the next page.

Optimum tank flatness results can be given by stating that 75^{o}/o of the observed values are within 2^{o}/o of observed average value.

Normalized Probe Readings as a Function of Frequency