BEAM ENERGY MEASUREMENTS ON THE RUTHERFORD LABORATORY P. L. A.

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I. Introduction

The results to be described are from measurements made using the time-of-flight method described previously,[1] and are a continuation of the work reported at other accelerator conferences.[2,3] As a result of recent observations some of the work reported previously needs some qualification. In particular, the 10 MeV and 30 MeV spectra have previously been affected by the residual power in Tanks 2 and 3 which results from the drive power feeding through the grounded grid triode amplifiers into these cavities even though the E. H. T. is removed from the amplifiers. Also early comparison between theory and practice from the 10 MeV beam has been invalidated by the fact that the field law in Tank 1 was distorted from its original value, which was used in the computer program. These effects are discussed below.

II. Effect of Residual Power on the Beam

Figure 1 shows the layout of the rf system of the P. L. A., for reference. The effect on the 10 MeV beam of varying the amplitude of residual power in Tanks 2 and 3 respectively, with these tanks maintained at the correct resonant frequency, is shown in Figs. 2a and 2b. The level of residual power was varied by means of the variable attenuators Att 2, Att 3 in the power dividing network. The effect of varying phase was found by setting the attenuators at their normal operating values, and detuning each tank in turn. The resulting spectra are shown in Figs. 2c and 2d for detuning of Tank 2 and Tank 3 respectively. It can be seen that the residual power affects the spectrum shape and position quite considerably. For normal settings of attenuators and frequency tuners the residual voltages were 6.4% of operating value in Tank 2, and 8.8% in Tank 3 (see Fig. 2). An amplitude reduction by a factor 0.7 (to give 'half power point' amplitude) produced a doubling of the beam energy spread at FWHH, and a small shift of mean energy $\sim$50 keV by each tank. A detuning of $\pm$ (f/2 Q) $\equiv \pm 45^{o}$ (to give the same reduction in amplitude, but now plus a phase shift) produced a change in beam energy spread at FWHH by a factor 3 (+ 45^{o}), 0.6 (- 45^{o}) by Tank 2, and 3 (+ 45^{o}), 0.5 (- 45^{o}) by Tank 3, and a shift of mean energy of + 20 keV (+ 45^{o}) by Tank 2, and - 40 keV (+45^{o}), - 120 keV (- 45^{o}) by Tank 3.

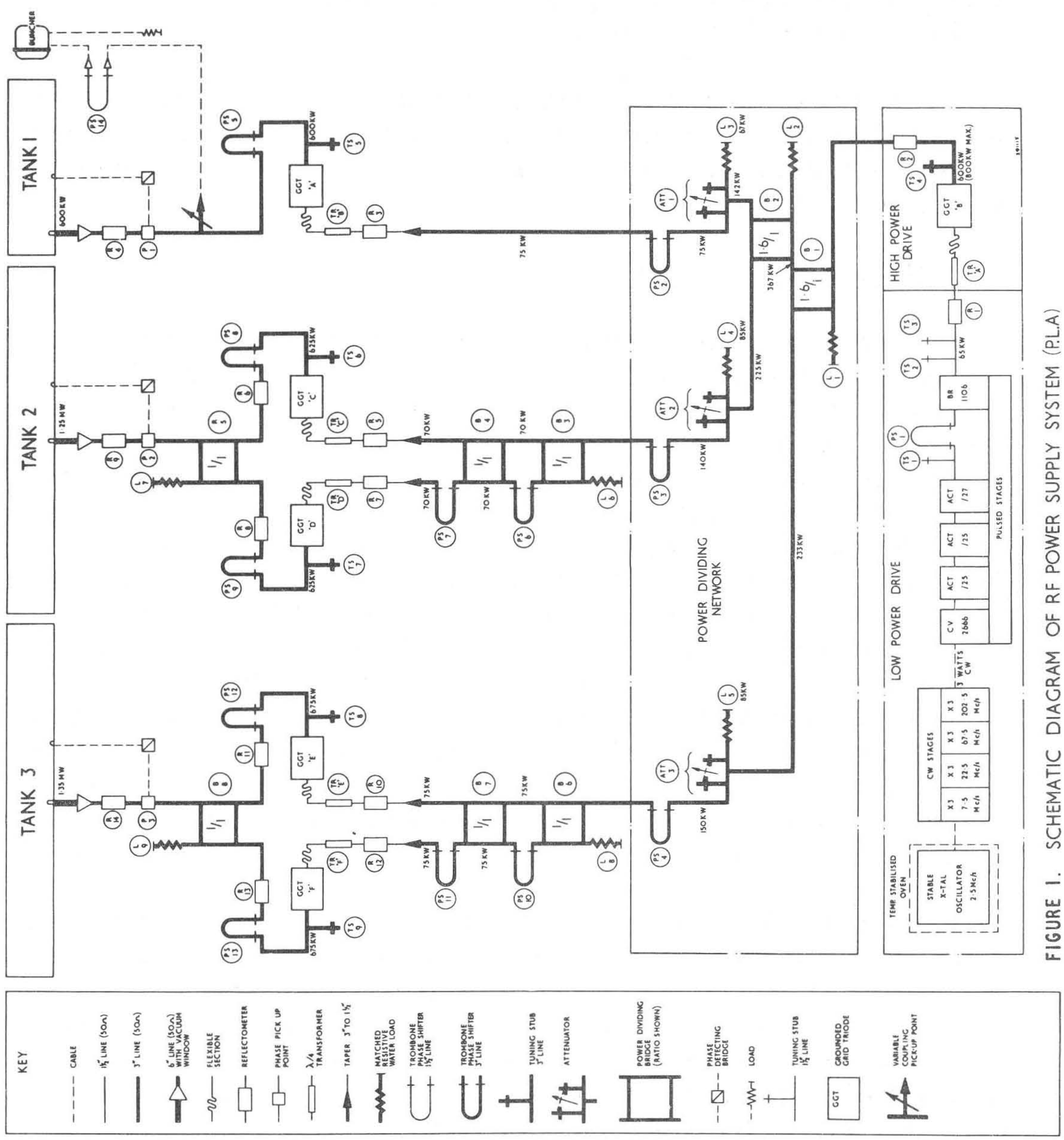

FIGURE 1. SCHEMATIC DIAGRAM OF RF POWER SUPPLY SYSTEM (P.L.A)

Figures 3a and 3b show the effect of residual power in Tank 3 on the the 30 MeV beam. For normal settings of the attenuator and frequency tuner of Tank 3, the residual voltage was 10% of operating value. An amplitude reduction by 0.7 produced little or no effect on the 30 MeV beam energy spread, but a shift of 120 keV. Detuning by $\pm 45^{o}$ produced marginal changes in energy spread, and a shift of mean energy - 350 keV ($+ 45^{o}$) and + 50 keV ($- 45^{o}$).

It is now normal operating procedure to reduce the residual power to a minimum in nonoperating cavities, this being achieved by detuning the tanks and insertion of maximum attenuation in the drive lines to the grounded grid triodes.

III. Measurements on Tank 1

Due to the discovery of the effect of residual power on the spectra it was decided that some of the early work on the 10 MeV beam should be repeated to try to improve the agreement between theory and practice which, at this energy, had not been good. Figure 4 shows some typical spectra for different injection energies and rf field levels, the tilt tuners being set at their assumed "flat field" setting (tilt 50-50). Computed spectra and phase acceptance did not agree well with measured values. Also the transparency of the tank was down by a factor 5 on its original value. It was therefore decided to remeasure the axial field in Tank 1 to see if this could be the cause of the disagreement. The field law measured for "tilt 50-50" is plotted in Fig. 5 and is compared with the field law measured when the cavity field was set up seven years ago (i.e., the field law used for computer calculations). It can be seen that gross distortion of the field has occurred, probably due to a change of dimensions caused by temperature cycling and periodic dismantling over the past seven years.

The actual measured field law has been used in the computer program to give comparison with some of the measured data of Fig. 4, and the computed spectra are given in Fig. 6. The experimental spectra of Fig. 4 do not show the same fine structure as the computed spectra, due to "smoothing out" by jitter in rf level and phase, and injection energy. But, with this proviso, comparison of corresponding spectra (A, B, C, etc.) now shows quite good agreement.

The field law has been restored to the proper value shown in Fig. 5. The transparency of Tank 1 has returned to its original value (i.e. 1/50). Results for the new field setting are not yet available.

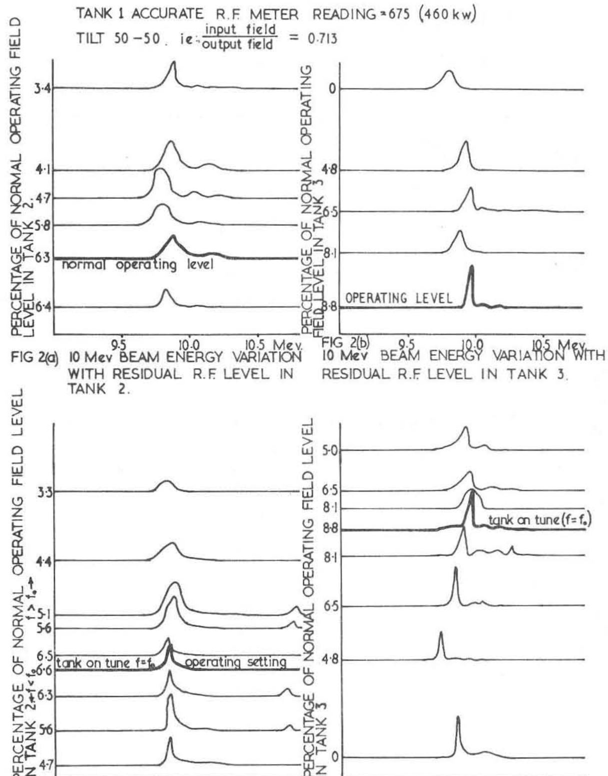

FIG 2(a) 10 Mev BEAM ENERGY VARIATION WITH RESIDUAL R.F. LEVEL IN TANK 2.

FIG 2(b) 10 Mev BEAM ENERGY VARIATION WITH RESIDUAL R.F. LEVEL IN TANK 3.

FIG 2(c) 10 Mev BEAM ENERGY AS A FUNCTION OF TUNER SETTING FOR TANK 2.

FIG 2(d) 10 Mev BEAM ENERGY AS A FUNCTION OF TUNER SETTING FOR TANK 3.

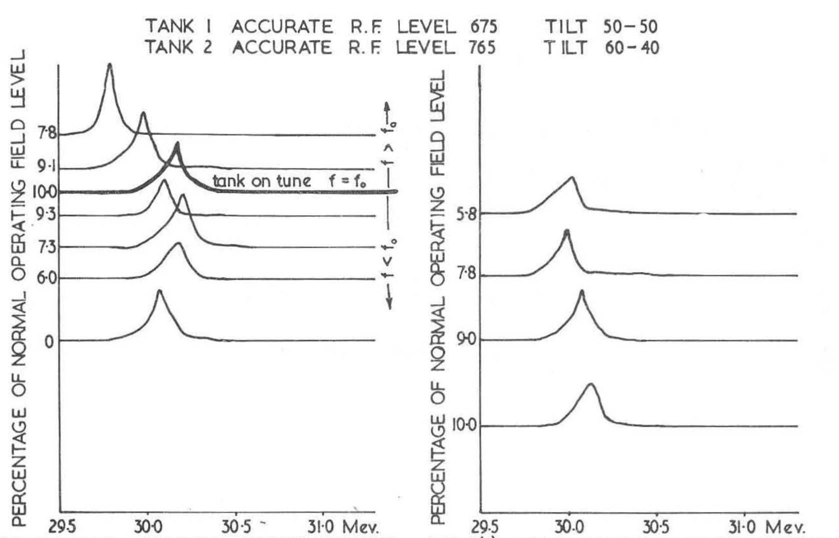

FIG 3(a) 30 Mev ENERGY v TUNER SETTING IN TANK 3

FIG 3(b) 30 Mev ENERGY v RESIDUAL POWER IN TANK 3

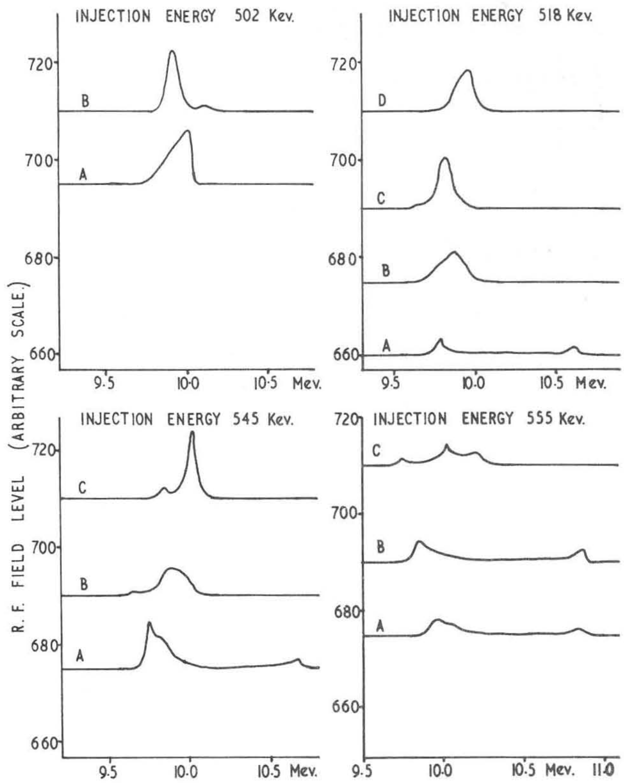

FIG 4. 10 Mev. ENERGY AS A FUNCTION OF R.F. LEVEL IN TANK 1 AND VARIOUS INJECTION ENERGIES.

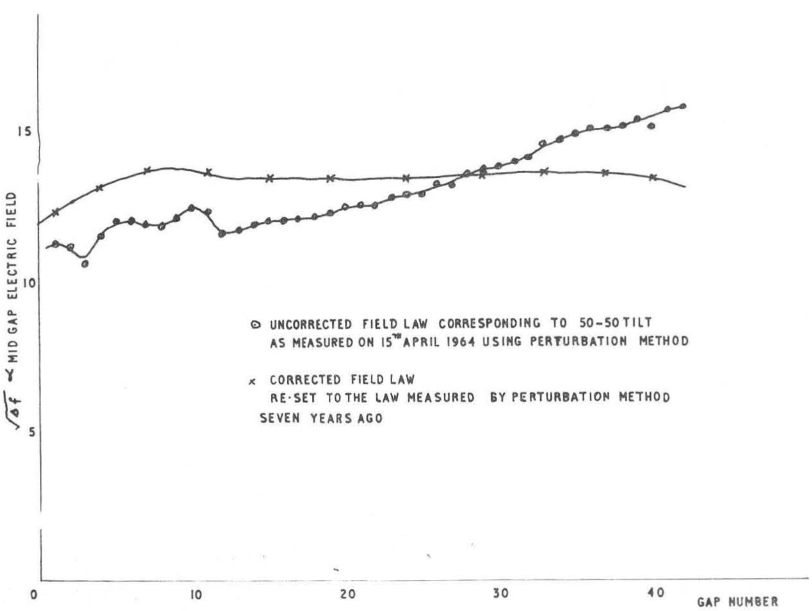

FIG 5. AXIAL FIELD LAWS FOR TANK I (BEFORE AND AFTER CORRECTION)

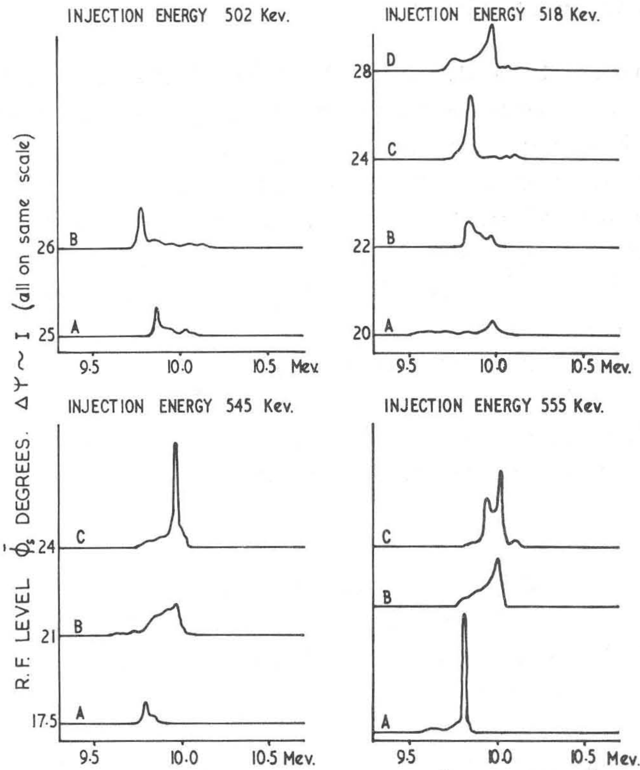

FIG 6. BEAM ENERGY IN TANK 1 [THEORETICAL]

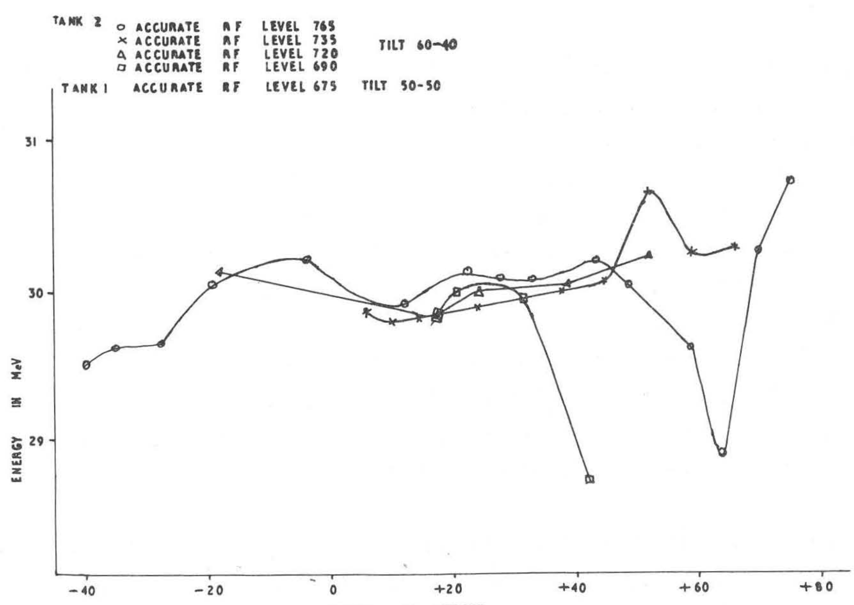

FIG 7 30 MeV ENERGY V INPUT PHASE

IV. Setting of Tanks 2 and 3

Before correcting the field law for Tank 1 measurements on the 30 MeV and 50 MeV beams were made to determine good operating levels of Tanks 2 and 3 for minimum energy spread in the beam. For the 30 MeV beam it is possible to run Tank 2 at an rf field level which gives an integral number of phase oscillation half wavelengths along the tank, and hence a flat energy vs. input phase region for the linear phase oscillation range of $\phi_s \pm 15^{o}$. Additionally it is required that the beam energy spectrum should be narrow. Figure 7 shows the variation of output energy with input phase: in particular, the rf level 735 is nearest to the required condition. The effect of input phase on output energy for the chosen rf level in Tank 2 (735) is plotted in Fig. 8, showing a roughly constant energy over the phase range, with little change in energy spread.

In Tank 3 it is not desirable to operate at a level corresponding to an integral number of phase oscillation half wavelengths, since the $\lambda_\phi/2$ level is too near threshold for acceleration, and the 2 $\lambda_\phi/2$ level is such that sparking would occur in the tank. Thus Tank 2 is operated at a different level (765) to give nearly integral number of phase oscillation half wavelengths between the input of Tank 2 and the output of Tank 3. The resulting 30 MeV spectra as a function of input phase to Tank 2 are shown in Fig. 9; the 50 MeV spectra versus input phase to Tank 3 is shown in Fig. 10. Finally Fig. 11 shows the energy spectra as a function of rf level in Tank 3.

V. Tank Tolerances

From the above results it is possible to make estimates of the stability of the output beam in terms of mean energy and energy spread as functions of machine parameters. Also use has been made of the Beam Energy Monitor described by Hanna and Hodges[4] to complete some of the results not determined by time-of-flight methods. This monitor, which utilizes a combination of degrading wedges for range determination, and a split ion chamber as a detector system, is very useful for determining mean energy, and can measure shifts of the order of 5 keV. A set of measurements with this monitor takes only a few minutes compared with several hours by time-of-flight methods. In the future the energy monitor will be used as a survey instrument to determine machine conditions worthy of further investigation by the longer method.

The following tables summarize the effect of injection energies, rf field levels and intertank phases on the output energies of the P. L. A., for the settings specified in Section IV.

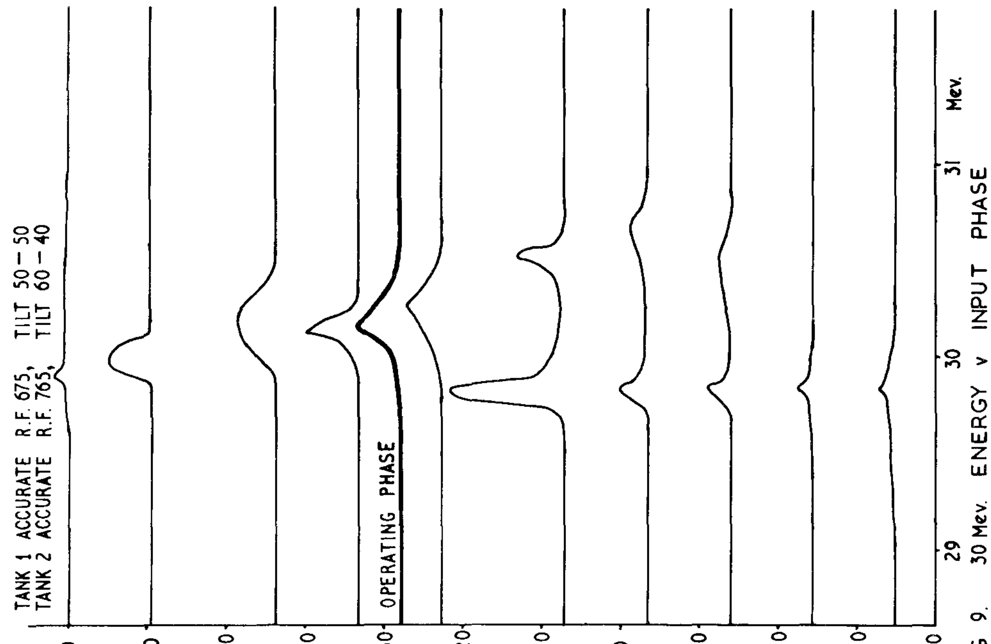
TANK 1 ACCURATE R.F. 675, TILT 50 - 50
TANK 2 ACCURATE R.F. 765, TILT 60 - 40
OPERATING PHASE
PHASE IN DEGREES
ENERGY v INPUT PHASE
30 Mev.
Mev.

FIG 9.

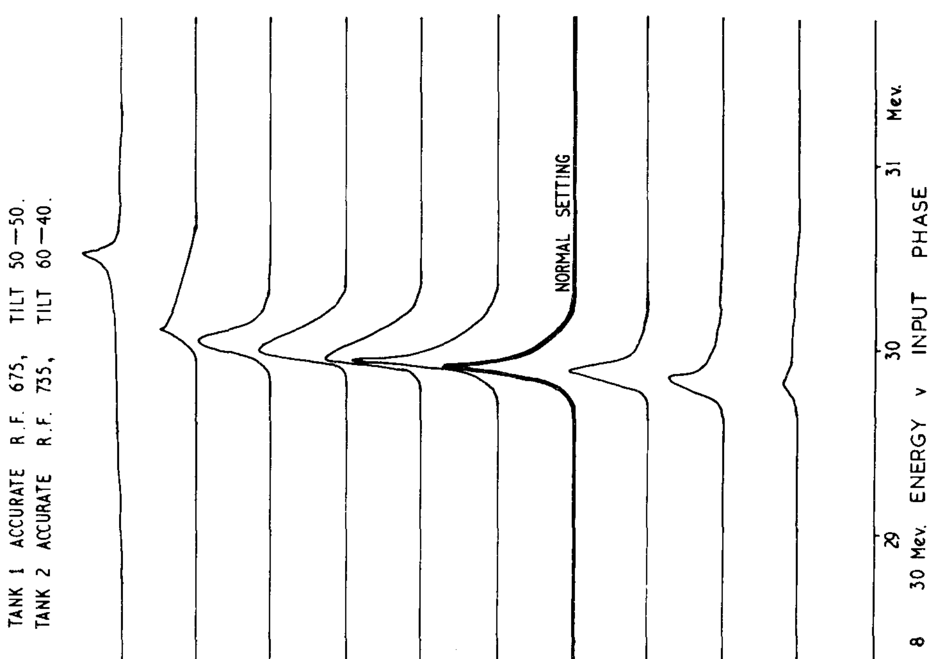
TANK 1 ACCURATE R.F. 675, TILT 50 - 50.
TANK 2 ACCURATE R.F. 735, TILT 60 - 40.
NORMAL SETTING
PHASE IN DEGREES
ENERGY v INPUT PHASE
30 Mev.
Mev.

FIG 8

Tolerances on Various Machine Parameters Affecting the Output Energies of the P. L. A.

(a) Injection Energy

Change of Injection Energy %	kV	Output Energy MeV	Change in Mean Energy keV	Measured by
		10	Not measured yet	
		30	Not measured yet	
+1	+5	50	-12 (-0.024%)	B. E. M.
-1	-5	50	+12 (+0.024)	

(b) RF Levels

Change in RF %		Acc. RF	Output Energy MeV	Change in Mean Energy keV	Measured by
Tank 1	+1	+5.5	10	-30 (-0.3%)	T. o. F.
	-1	-5.5	10	+30 (+0.3%)	
	+1	+5.5	30	-25 (-0.08%)	T. o. F.
	-1	-5.5	30	+25 (+0.08%)	
			50		
			50	Not yet measured	
Tank 2	+1	+8	30	+80 (+0.27%)	B. E. M.
	-1	-8	30	-80 (-0.27%)	
			50	Not yet measured	
Tank 3	+1	+9	50	0	B. E. M.
	-1	-9	50	-50 (-0.1%)	

(c) Intertank Phases

	Change in Intertank Phase. Degrees	Output Energy MeV	Change in Mean Energy keV	Measured by
Tanks 1/2	1°	30	24 (0.08%)	B. E. M.
	1°	50	18 (0.036%)	T. o. F.
Tanks 2/3	1°	50	45 (0.09%)	

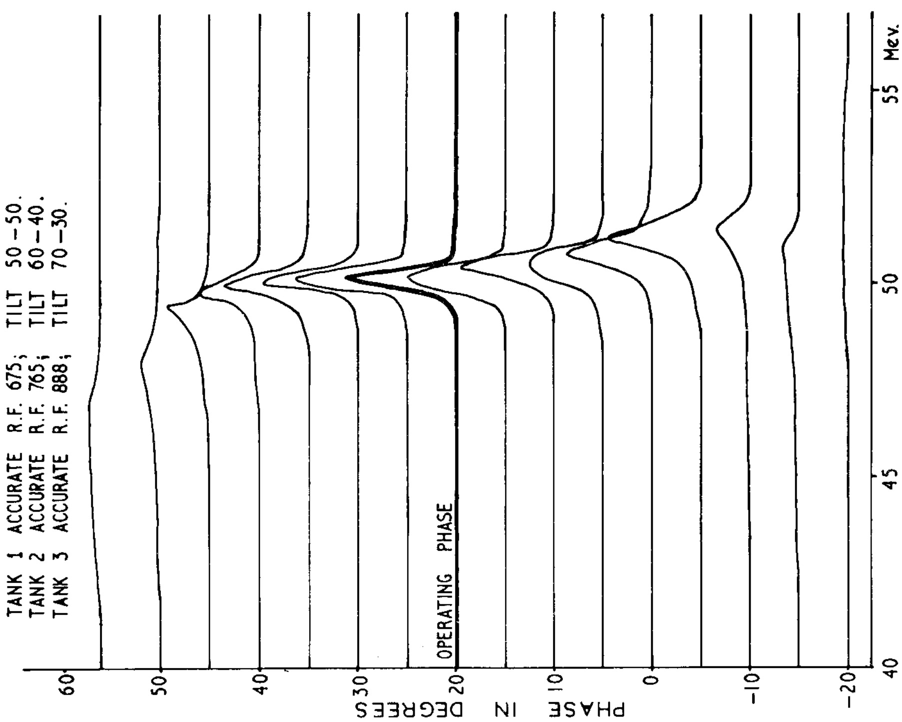

FIG 10. 50 Mev. ENERGY v INPUT PHASE

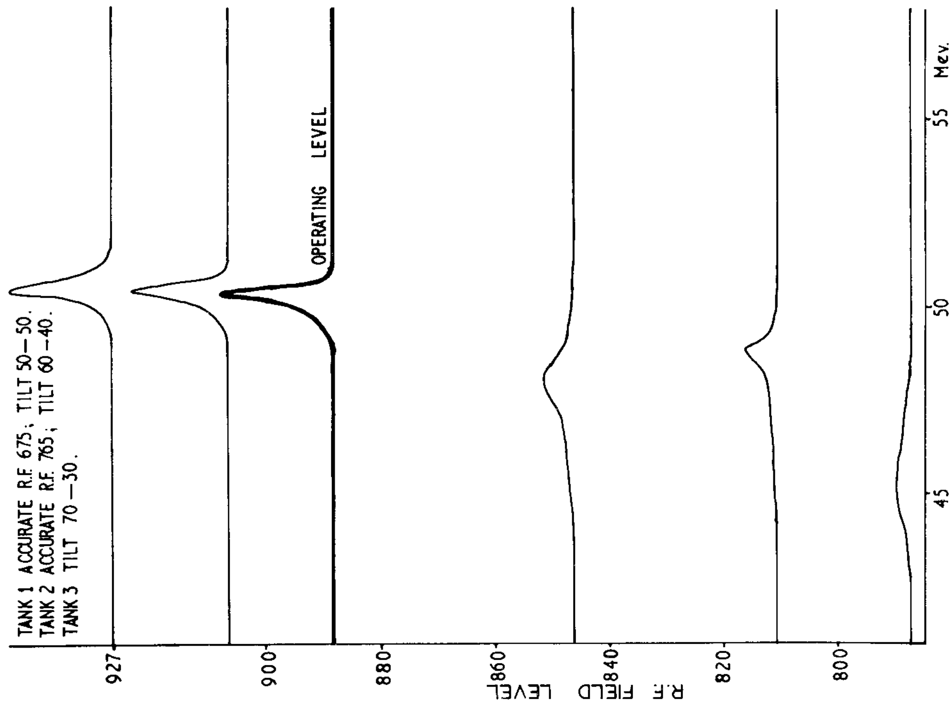

FIG 11. 50 Mev ENERGY AS A FUNCTION OF R.F. LEVEL IN TANK 3

Conclusions

The change of energy and energy spread in a beam drifted through a cavity containing some residual rf power has been shown to be such as to cause concern if a precise output spectrum is required.

Agreement between computation and experiment at 10 MeV has been improved, after finding the actual field law in Tank 1. This field law has now been set to its correct value, and it is intended to check the field laws in Tanks 2 and 3 in the near future.

The settings and tolerances given for the P. L. A. represent the state of the art at the present time. Detailed work is continuing, by the use of the Beam Energy Monitor and time-of-flight apparatus, to determine more closely the optimum operating conditions.

Acknowledgements

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TENG: Do you understand all these?

CARNE: Well, certainly the agreement between axial motion computations and the experiment is quite good. This is particularly true in the case of tanks two and three, where we have used a large signal calculation, that is, a 32 step-by-step integration per cell. The agreement in tank one is now quite good and we think we can improve the situation. We think in terms of phase oscillation wavelengths, and the picture ties up fairly well.

TENG: The shifts you are talking about are very large, 50 kV in 50 MeV.

CARNE: Sure that's alarming, but these figures in fact agree with equations given by Lloyd Smith some time ago in LS-3. These give quite tight tolerances.

WHEELER: When you change the level in a cavity by say 1%, did you change the phase between the cavities to compensate for the change in the position of the bucket?

CARNE: No.

LAPOSTOLLE: When you spoke about the inference of residual field in tanks two and three on measurements done at 10 MeV, do you think that even the field induced by the beam could affect such measurements?

CARNE: There could be some effect, but as John Dickson said earlier, we have a peak current of the order of 200 μA, so that fields induced by the beam are of the order of a factor 1000 down on the residual fields in the cavities, where there are still a few kilowatts of rf power.

TAYLOR: I will just mention that we have had exactly the same effect. Unless we drop the field to zero, we find that the measurements are turned about all over the place and we have a high current too.

REFERENCES

1. An Accurate Determination of the P.L.A. Beam Energy by a Time of Flight by C. J. Batty and D. J. Warner. NIRL/R/9.

2. Accurate Energy Measurements on a 50 MeV P.L.A. report submitted to 1963 Accelerator Conference in Dubna U.S.S.R. (Also P.L.A. Acc/Phys. 18).

3. Beam Observations in the P.L.A. by K. Batchelor, A. Carne, J. Dickson and D. J. Warner. Report on 1962 Conference on Linear Accelerators for High Energies at Brookhaven National Laboratory. BNL 6511.

4. A Beam Energy Monitor by R. C. Hanna and T. A. Hodges. P.L.A. Progress Report 1963 NIRL/R/50.