THE CERN-PS LINAC - BEAM LOADING AND RF STUDIES

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ABSTRACT

The CERN-PS linac is at present accelerating currents of the order of 60 mA and partial compensation of the beam loading is being provided by "bumps" on the rf pulses. The evolution of this type of compensation is described and the results of energy spread and emittance measurements with and without compensation are presented.

An alternative method of supplying beam power from a supplementary power source is considered and preliminary tests are described.

Measurements of the phasing between tanks and the velocity of propagation of fields along the walls of the cavities are also reported.

I. INTRODUCTION

Beam loading in the accelerating cavities first became detectable in the rf envelopes with beam currents around 15 mA, and in 1961 attempts were made to compensate the fall in field during the beam pulse by moving the beam to the rising edge of the tank field and increasing the level. At that period, however, there was a 20 μs jitter in the initial rise of field in the 10 MeV tank, attributed to multipactor effect, and this jitter resulted in wide variation in accelerating field level and consequently in linac beam quality and PS intensity. The increased level also encouraged sparking although that could have been overcome by shortening the rf pulse.

Efforts were then directed towards supplying more power to the cavities during the beam pulse with the beam restored to its normal position near the end of the rf build-up.

II. EVOLUTION OF PRESENT METHOD OF COMPENSATION

In July 1962, attempts were made to increase the plate voltage of the TH 470 power amplifiers at the moment of beam injection. It was found that, with some sacrifice of pulse length, we could produce a useful "bump" on the anode pulse by increasing the terminal capacitor of the modulator delay line as shown in Fig. 1.

This method was applied first to the modulator of the three final amplifiers (see Fig. 8 for a general schematic of the rf system), and then extended to the drive modulator, both to increase the tank bumps and to suppress the over-voltages which appeared as a result of pulse length disparities.

The next step was to decrease the cathode bias voltage simultaneously with the anode bump by firing a hydrogen thyratron connected in parallel with part of the cathode resistor (Fig. 2). Careful adjustment of this combination of anode voltage and cathode current bumps led to the present situation, where a beam of 30-35 mA can be fully compensated in each of the three tanks.

It has been found convenient to assess these effects by displaying the time derivative of the tank field rather than the field itself. Both signals are shown in Fig. 3. Knowing the beam current we can immediately calibrate our signal and derive the percentage compensation for any given rf adjustment.

III. BEAM QUALITY WITH PRESENT METHOD

For the case of a beam pulse short by comparison with the cavity time constant, it can be shown by approximate solution[1] that the beam produces a change of accelerating field

$$\frac{\Delta V}{V_o} = - \frac{P_b}{2 W_o} t$$

where P_b is the instantaneous power delivered to the beam and W_o is the cavity stored energy at $t = 0$, and a change of phase

$$\Delta\varphi = - \frac{P_b \tan \varphi_s}{2 W_o} t$$

where φ_s is the synchronous phase angle.

Since this phase term is roughly the same for each of the three tanks (about 2.5^o for 50 mA), the original phase relations between the tanks will be preserved during the passage of beam, although not necessarily between the last tank and the debuncher.

The more significant effect of field change we should expect to be equivalent to a change of synchronous phase angle during the pulse and in our case on uncompensated 50 mA should produce an 8% change in $\cos \varphi_s$, for example from $\varphi_s = 30^o$ to $\varphi_s = 21^o$, and detectable changes in energy spread and emittance.

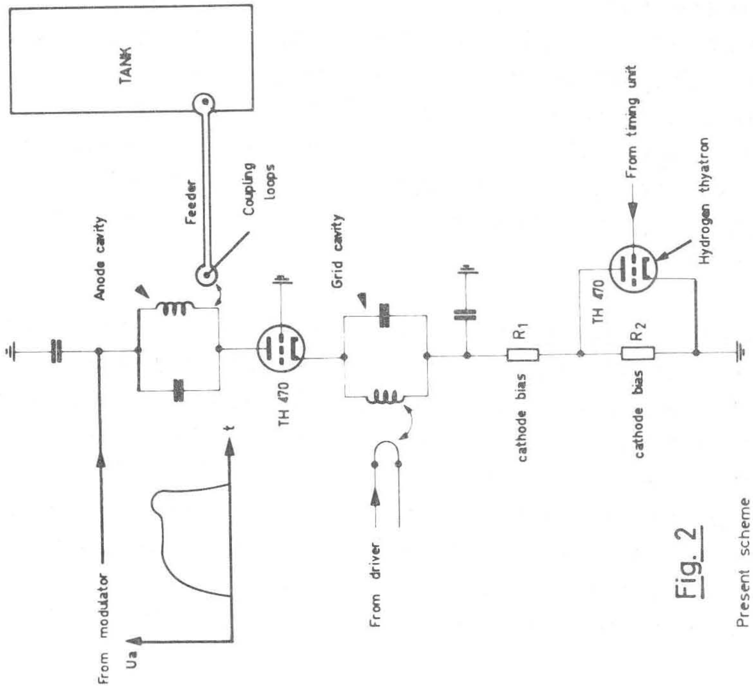
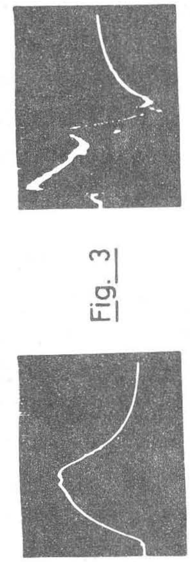


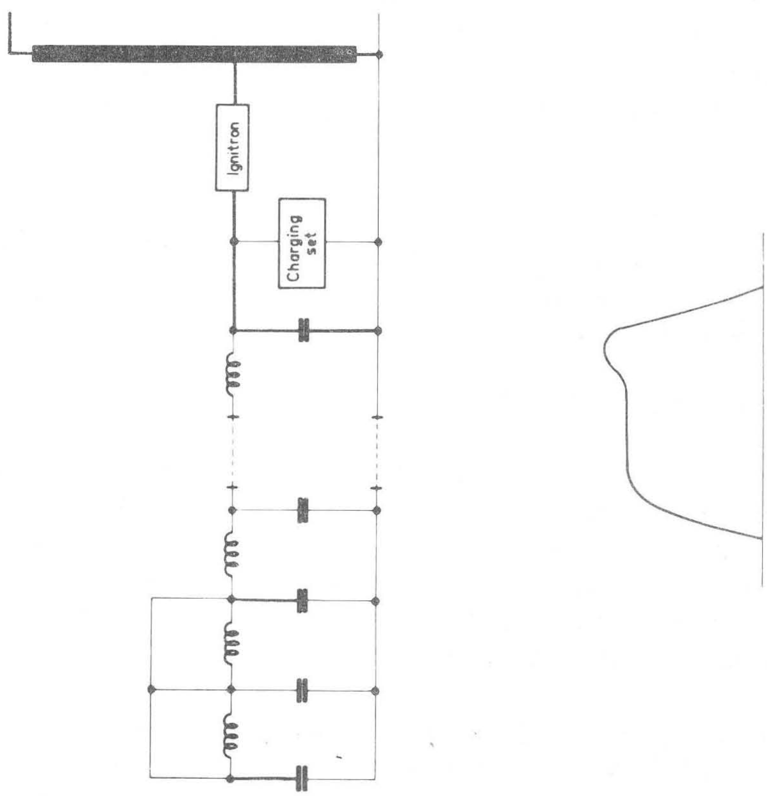
Fig. 2 Present scheme



Accelerating voltage : V

derivative : $\frac{dV}{dt}$

Fig. 3



Resulting anode pulse

Fig. 1 Modified delay - line

In Fig. 4a we see the measured energy spectra for an uncompensated 55 mA beam and for a beam compensated to an average value of 50% in the three tanks, with and without debuncher. It is evident that the debuncher is doing all the real work but that changes during the pulse are reduced by the compensation. The uncompensated beam is in fact not very satisfactory since particles are lost at the end of the pulse in the linear accelerator itself, the end of the pulse being only one-half the height at the beginning.

The experimental arrangement comprised a 0.5 mm object slit, approximately unity magnification, a 1 mm resolving slit equivalent to $\pm$ 30 kV, and about 6 mA of total beam current, with this reduced current passing through the debuncher. This resolution is not adequate for small energy spreads and the energy spread may be less than that measured. However, from the point of view of what the synchrotron actually sees with 60 mA, this error may be countered by the deterioration of the energy spread due to the reactive beam loading in the debuncher which we estimate to change the phase by some 10° and to add 80 kV to the energy spread.

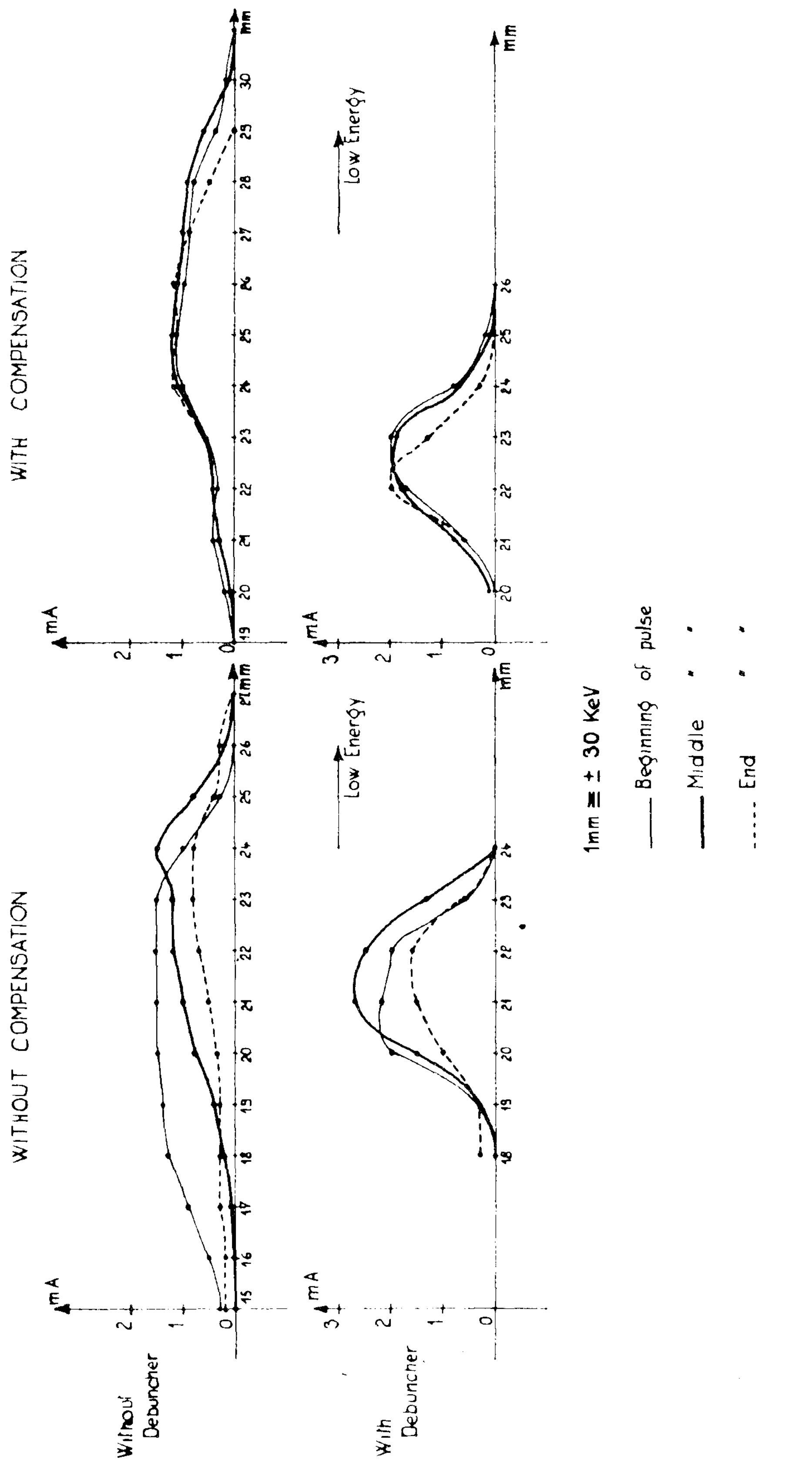
In Figs. 4b and 4b' we see the emittance plots for the same condition of no compensation and 50% compensation. The horizontal plane (emittance Y) appears to be subjected to a clockwise rotation with time whereas this effect in the vertical plane (emittance Z) is much less marked. The distorted envelope for the end of the pulse in "emittance Y without compensation" probably indicates aperture limitations in the linear accelerator.

Care was taken during these measurements to keep the rf field constant in the middle of the pulse. However, the emittances with and without compensation in the middle of the pulse are not identical and this requires further investigation.

IV. SUPPLEMENTARY POWER SOURCE

In order to drive a 50 mA beam through the 30-50 MeV tank, we need 1 MW of rf power, and since this tank dissipates 1.5 MW, the total instantaneous power requirements are already beyond the capacity of our 2 MW amplifiers. If, however, we separate the functions of feeding losses and feeding beam power, we should be able to approach 100 mA beam currents with our present amplifiers.

Our present proposal is to drive the tank up to operating level by means of the existing delay line modulator, and then to supply the beam power by means of a second coupling loop and power amplifier for the



50 MeV ENERGY SPECTRA

Fig. 4A

duration of the beam pulse. We propose a hard-tube modulator for the beam power pulse, with the possibility of servo control from the beam current. One advantage of this system is that the phase of the beam power source can be varied with respect to that of the main source, i.e., power can be fed to the beam with the accelerating voltage in phase with the beam current Fourier fundamental φ_s from the crest.

The proposed scheme is shown in Fig. 5.

Preliminary tests of such a system have been made on the 30-50 MeV tank. The beam power amplifier was excited by rf power taken capacitively from the main loop feeder, and a modulator was modified to provide a short anode pulse (Fig. 6). Using the normal 200 μs pulse transformer, we could not obtain a very satisfactory rise time. Nevertheless full compensation of a 60 mA beam was obtained (Fig. 7). Unfortunately beam quality checks could not be made in the time available, apart from a quick measurement of energy spread which appeared to be normal.

V. PHASING BETWEEN TANKS

The three accelerating cavities are each held at a fixed phase by means of a phase servo loop. Line lengtheners in the final amplifier grid circuits are coupled mechanically to line lengtheners in the phase reference lines and this arrangement permits relative movement of the tank phases (see Fig. 8: Schematic of complete rf system).

A good beam can be obtained by a purely empirical adjustment of relative phases. Alternatively, one can employ a criterion based on the 3 φ_s trapping width. In the early experiments it was accepted *a priori* that the correct adjustment was the "in-phase" condition although some attempts to measure relative phases with hybrid ring bridges gave conflicting results. With, however, the installation of accurately adjusted cables and a lissajous figure type of phase comparison (Fig. 9), it has become fairly certain that the beam likes best to find the 10 and 50 MeV tanks in phase but the 30 MeV tank advanced by some 25°, that is, this dephasing produces the best energy spread.

There is as yet no satisfactory explanation of this effect. One possible contribution comes from the two-cell drift distance between the first and second tanks, combined with the fact that we normally inject our bunched beam into the first tank well above the center of the rf bucket in order to profit from the higher trapping. However, our step-by-step computations using the program developed at Harwell by Taylor and Carne show that the energy error resulting at 10 MeV is only about

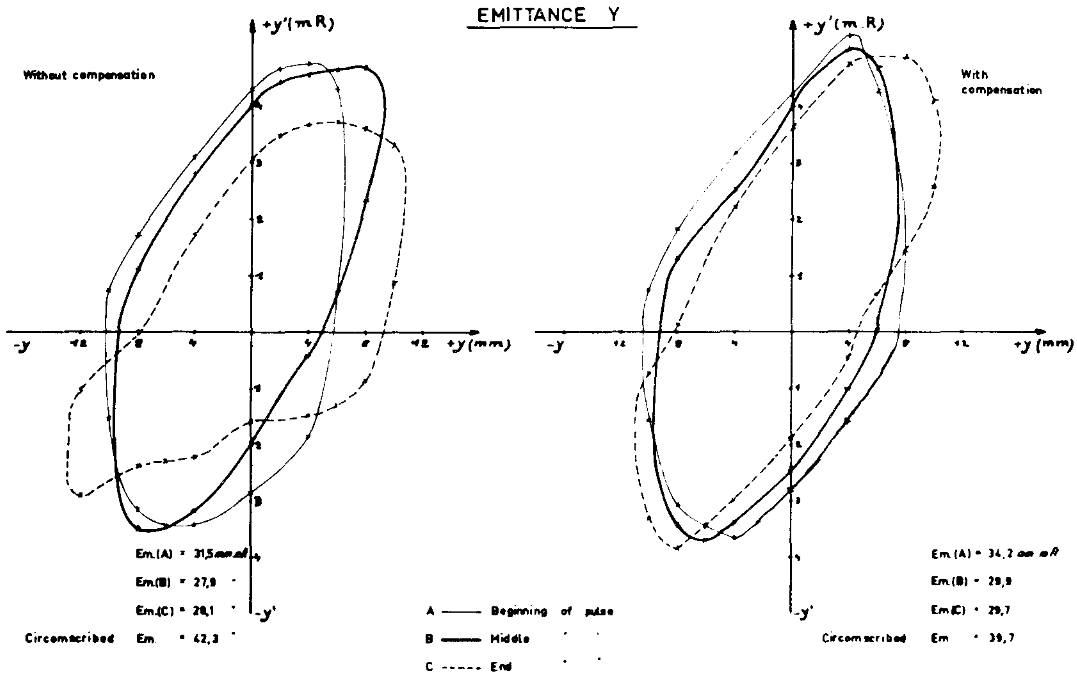

EMITTANCE Y
Without compensation
With compensation
+y'(mR)
-y
+y (mm)
-y'
Em.(A) = 31,5 mm.mR
Em.(B) = 27,9
Em.(C) = 28,1
Circomscribed Em = 42,3
Em.(A) = 34,2 mm mR
Em.(B) = 29,9
Em.(C) = 29,7
Circomscribed Em = 39,7
A —— Beginning of pulse
B —— Middle
C ----- End

Fig. 4b

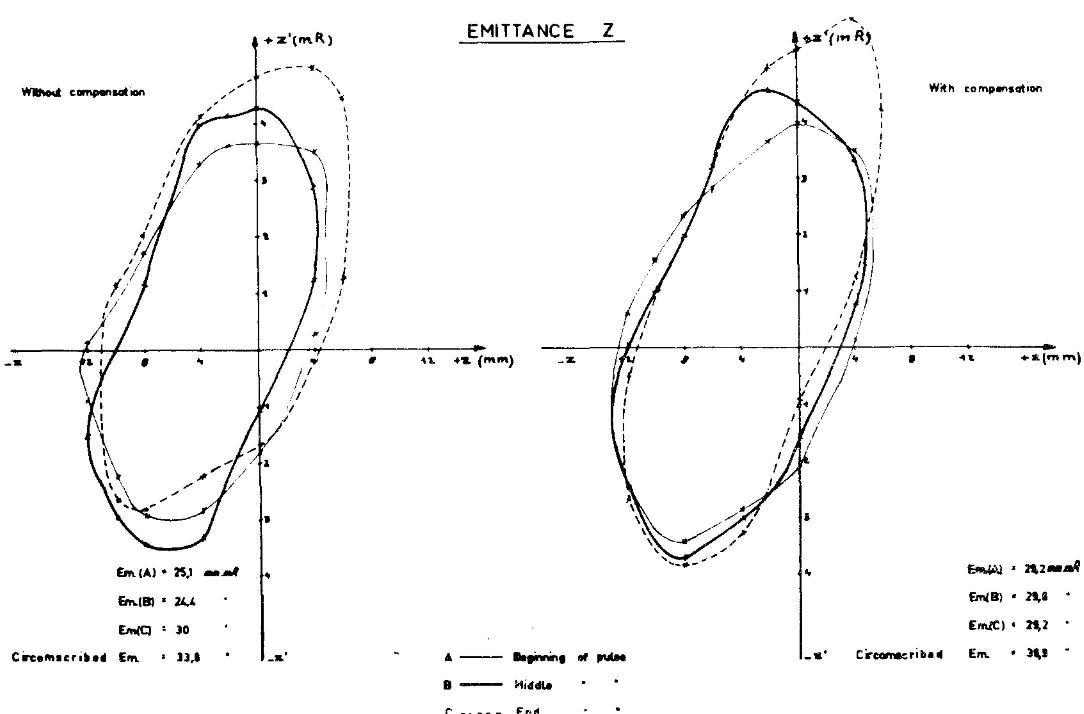

EMITTANCE Z
Without compensation
With compensation
+z'(mR)
-z
+z (mm)
-z'
Em.(A) = 25,1 mm.mR
Em.(B) = 24,4
Em.(C) = 30
Circomscribed Em = 33,8
Em.(A) = 28,2 mm.mR
Em.(B) = 29,6
Em.(C) = 28,2
Circomscribed Em = 38,9
A —— Beginning of pulse
B —— Middle
C ----- End

Fig. 4b'

100 kV, and produces a phase error due to the drift distance of only 3 or 4 degrees.

Another possibility, which came out of a discussion with Teng and Lapostolle, is that we are exploiting the nonlinear region of the Tank II bucket to spread the bunch out, and then rotating this elongated bunch around to the position of minimum 50 MeV energy spread by adjustment at Tank II and III levels, thereby varying the number of phase oscillations in these tanks. This mechanism would require an integral number of wavelengths in Tank II and an odd number of quarter wavelengths in Tank III.

VI. PROPAGATION

Recent discussions of group velocities[2] have led us to compare the build-up of tank fields at the extremities of the 30-50 MeV tank (with power fed in at one end). Using the phase measurement loops and cables we have employed the chopped beam facility of an oscilloscope to superimpose the detected signals from both loops. In Fig. 10, we see the field signals and the initial build-up on a shorter time base. From these oscillograms one can put an upper limit of a microsecond on the delay and a lower limit of 10^7 m/sec on the corresponding velocity for field propagation along the cavity walls.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the excellent contributions of Messrs. Block, Marti, Têtu and Weiss to the experimental work and computations.

TURNER: Could you repeat the specifications for the new FTH 515 tube you mentioned?

TAYLOR: 4 MW peak power; heater, 12 kW; anode dissipation, 11 kW. I think the drive power is 700 kW.

VAN STEENBERGEN: Do you have to make a modification to the tube cavity?

TAYLOR: No, the specification calls for a tube which is a mechanical plug-in replacement for the FTH-470. It will have the same anode volts but double the current. We will probably have to modify the loop and the coupling.

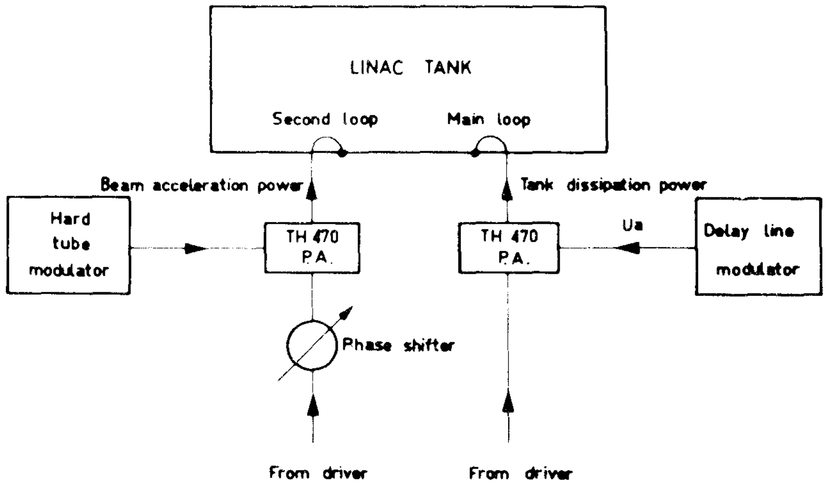


Fig. 5

Proposed scheme

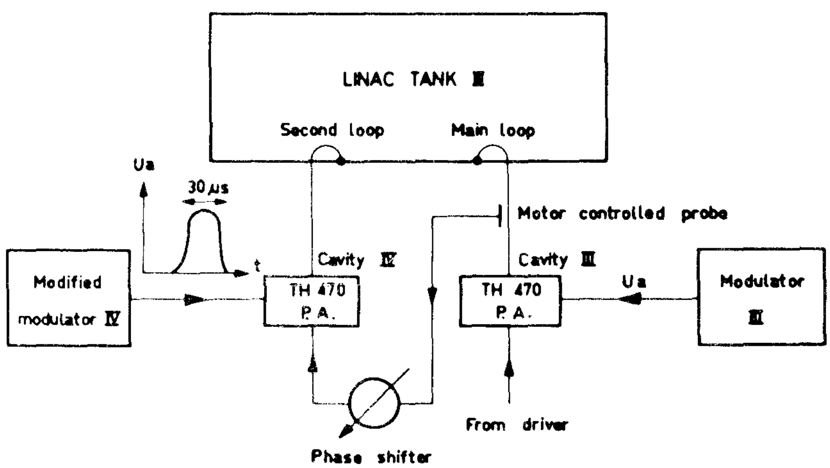
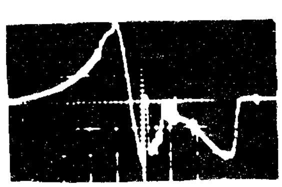


Fig. 6

Tested scheme



$\frac{dV}{dt}$ for a 50mA beam

Fig. 7

VAN STEENBERGEN: What is the promised delivery date on this tube?

TAYLOR: I think we should get a tube within about six months.

QUESTION: Have you watched some of the modeling on this tube?

TAYLOR: It is only just started. I might mention that the cost is something like $6, 500 per tube.

PERRY: I didn't understand the phase shift from 30° to 21°.

TAYLOR: This is simply the field going up and then dropping due to the presence of beam. This is equivalent to a change in the synchronous phase from 30° to 21°.

PERRY: When you have 50 mA beam loading and 8% droop, was the 30° to 21° the phase shift due to beam loading?

TAYLOR: The difference in cos φ_s was 8%.

KEANE: You mentioned that you had no phase or time delay in the field propagation along the tank. I have noted on Brookhaven's linac that we have at least 1-1/2 microsecond delay from the center drive point to both ends of the tank.

TAYLOR: In our measurement, the difference in path length is about 10 m. In your case it is 15 - 16 m.

MARTIN, J. H.: You used the term "compensated" and "uncompensated." Did that consist of anything besides just an additional bump at the end?

TAYLOR: No, that was simply a bump.

MARTIN: It had influence on the energy distribution and phase-space accommodation and so forth; did it have anything to do with the phase relations between the tanks?

TAYLOR: That occurs with a small beam. If we stop the beam down, we still have this effect.

MARTIN: So this effect is independent of beam loading?

TAYLOR: Yes.

KEANE: You mentioned that you used a separate amplifier for beam compensation. Did you have any trouble with power coupling between the loops of the two driving sources?

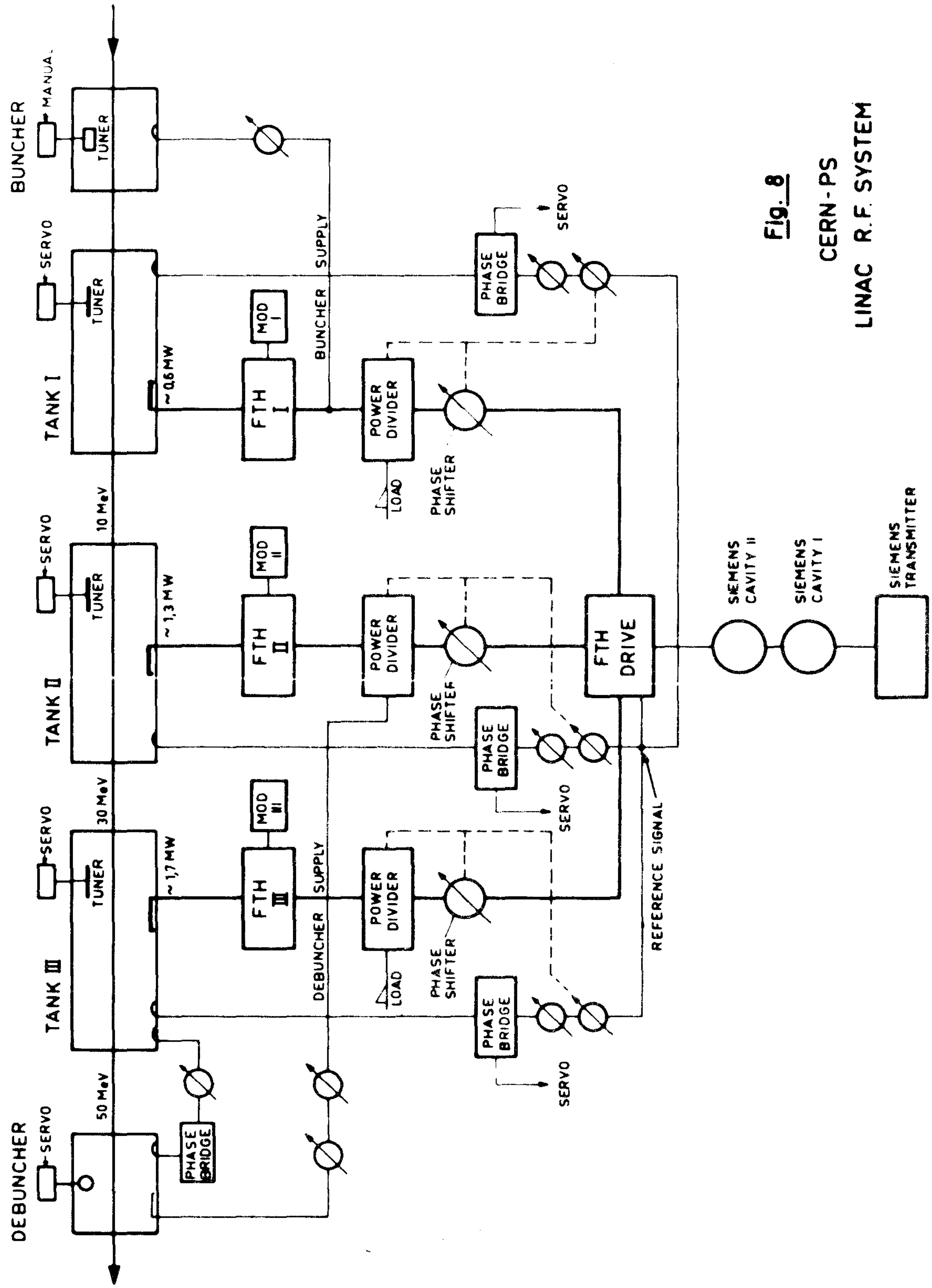


Fig. 8

CERN-PS

LINAC R.F. SYSTEM

TAYLOR: We were a little worried about this and our first move was to put a short circuit piston on the auxiliary loop. We made it as close to a short circuit in a tank as we could. Then we found that by moving this up and down, it made no difference. It is surprising. Then when we connected a FTH amplifier cavity in place of the short circuit, there was a tendency for it to "diode", and we found ourselves in a little bit of trouble getting enough power from the main amplifier.

KEANE: Were the loops the same?

TAYLOR: Exactly the same loop. It probably makes a terrible bump on the flattening, but so far we have not noticed it.

DICKSON: Going back to the phase changing in Tank 2, how do you find running all tanks in phase and adjusting the wave lengths of Tanks 2 and 3 together to get an integral half-wave length?

TAYLOR: We have tried to run them in phase and adjust the levels of all tanks together, but we went through a fair range and we could not find an energy spread as good as the energy spread which we get with the normal adjustment of the phasing.

REFERENCES

1. Y. Dupuis, Etude de la charge introduite par le faisceau dans les cavités H.F. du Linac du CPS. Internal report MPS/Int. LIN 36-8.

2. J. M. Dickson, Private communication.

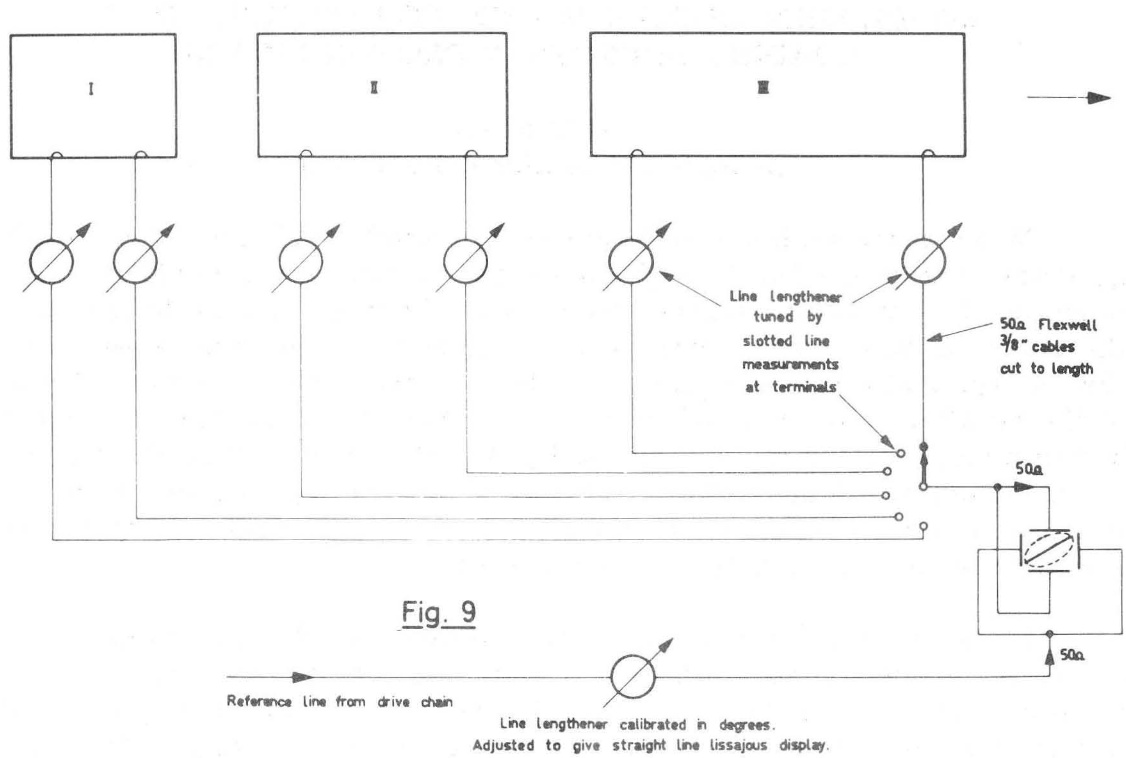
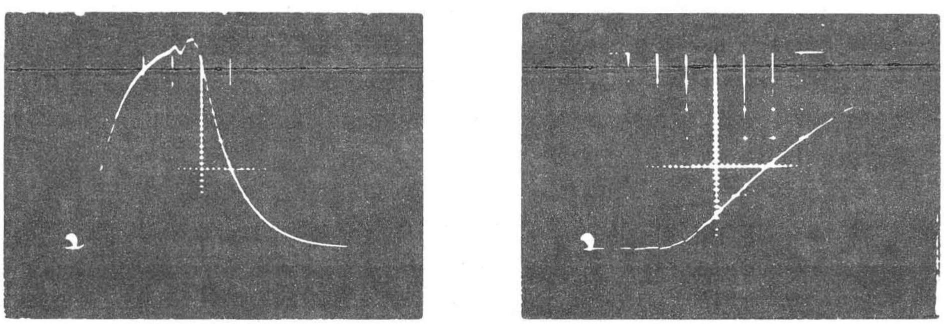


Fig. 9



0.5 V/cm 50 μs/cm
Chopped beam.
Equalisation of detector outputs.

A

As Fig 10 A but 10 μs/cm

B

Fig. 10