THE BROOKHAVEN 50-MeV LINAC RF MULTIPORT SYSTEM*

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Summary

A new high power RF system has been installed at the Brookhaven 50-MeV linac to accelerate the higher beam intensities now available from an improved preinjector.[1] Use has been made of the previous efforts of many people to reach a final flexible system design. Initial system operation to date has increased by a factor of two the linac output current intensity while obtaining an energy spread comparable to the one observed for lower currents.

Introduction

The Brookhaven 50-MeV linac RF system has been redesigned to accelerate higher intensity proton beams with a good energy spread. A 75 mA, 80 µs beam pulse is the expected operating current. It is desirable that the RF system be able to compensate for 100 mA for machine studies. As in the previous system beam loading compensation is accomplished by increasing the anode voltage on the power amplifier stages. Multiple feed ports (properly located) reduce unwanted transients which are excited by the compensation pulse[2-5] and reduce the operating gradients on the tank feed line(s). Maximum use of components from the old system was desirable and therefore the final amplifiers are TH515 triodes.[6]

System Design

The total power requirements for the linac cavity loaded with a 100 mA beam is approximately 8 MW. This could be supplied by two TH515 amplifiers operating at their recommended data sheet maxima. Three tank drive ports each powered by a TH515 triode are used and provide a conservative solution.

The ports are located at L/6, L/2 and 5L/6. Positioning the ports in this manner cancels the TM$_{01n}$ modes up to and including n = 5. Figure 1 illustrates this for n = 1, 2. The power in the frequency spectrum components above n = 2 is negligible. Figure 2 is a partial system schematic. The TH515's are operated drive saturated and the hard tube modulator (HTM) has a local voltage regulator. Expected conditions for a 100 mA beam are shown.

System Tuning

It is desirable to operate the 8-in. coaxial lines into a matched load during beam time. This condition can be satisfied by adjusting the operating frequency to compensate for the detuning effects of beam loading.[3,4,7] The variable tank coupling loops are then adjusted to match the beam-loaded tank to the coaxial lines.

Figure 3 gives a simple approximate equivalent circuit for estimating the operating frequency shift from unloaded tank resonance and the VSWR before beam turn-on. The reflected voltage at port A (all ports are operated with equal line lengths) is:

$$V_{AREV} = V_T - \frac{1}{2} V_1 \quad . \tag{1}$$

This can be shown to be:

$$V_{AREV} = \left[\frac{1}{N_A^2 + N_B^2 + N_C^2 + R_o Y_L} \right] \left[\frac{1}{2} \left[N_A^2 - (N_B^2 + N_C^2) - R_o Y_L\right] V_1 + (N_B N_A) V_2 + N_C N_A V_3 \right] \tag{2}$$

letting: $N_A = N_B = N_C = N$ (identical coupling)

$V_1 = V_2 = V_3 = V$ (balanced and phased drives)

$$V_{AREV} = \frac{1}{2} V \left[\frac{3N^2 - R_o Y_L}{3N^2 + R_o Y_L} \right] . \tag{3}$$

The reactive part of beam loading has been shown to be:

$$B_B = - \frac{\eta \tan \varphi_s}{R_s (1 - \eta)} \quad \text{(Refs. 7, 8)} \ . \tag{4}$$

The reactive part of a slightly detuned cavity is:

$$B_T = - 2Q\Delta f / R_s f_o \tag{5}$$

for resonance $B_B = - B_T$. This condition gives

$$\Delta f = - \frac{\eta f_o \tan \varphi_s}{(1 - \eta)\, 2Q} \quad . \tag{6}$$

Operating with no beam and off resonance and $N = \sqrt{R_o / 3R_s (1-\eta)}$ (loops adjusted for match during beam time) we get:

$$VSWR = \frac{|V_{AFWD}| + |V_{AREV}|}{|V_{AFSW}| - |V_{AREV}|} \tag{7}$$

$$VSWR = \frac{\sqrt{4(1 - \eta) \cos^2 \varphi_s + \eta^2} + \eta}{\sqrt{4(1 - \eta) \cos^2 \varphi_s + \eta^2} - \eta}$$

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For a beam current of 75 mA:

$$P_B = 3.75 \text{ MW}$$
$$P_T = 3 \text{ MW}$$
$$f_o = 201 \text{ MHz}$$
$$Q_o = 60{,}000$$
$$\varphi_s = 30^\circ$$
$$\text{VSWR} = 2.53; \quad \Delta f = -1.207 \text{ kHz}$$

Mechanical Design and Construction

Conversion of the existing RF system involved basically the coupling of power to the linac cavity at two additional locations, at L/6 and 5L/6. These sites were close enough to two of the twenty evapor-ion pump-out stations servicing the linac cavity to permit these stations to be used for RF coupler installations.

Some modification of the station ports, however, was necessary to accommodate loop couplers. Inside the port, opening into the cavity was through an hexagonal array of 109, ½-in.-diameter holes perforating the cavity wall. It was necessary to remove this perforated area, carrying the 10-in. inner diameter of the port through.

The cavity wall is formed of 7/8-in.-thick steel having an inside cladding of 5/32-in.-thick copper. In consideration of methods for opening up the wall, flame cutting was regarded as being unacceptable, principally for the risk entailed in distorting the cavity and misaligning the drift tubes within. Also, because of time allowance, it followed that in-place machining was the best approach.

This operation was performed by means of a vertical miller head removed from a portable unit. The miller was rigidly supported underneath each of the two ports by a 20-in. square X 36-in. high concrete pedestal, shown in Fig. 7. The pedestal is capped with level plate fastened to it at each corner by a tie rod which continues through the pedestal to anchor in the floor of the linac building. With this arrangement, a 9.812-in.-diameter hole was fly-cut vertically upwards through each port with no difficulty.

In its planning, it was proposed that certain mechanical components of the multiport system be designed to facilitate over-all tuning. The linac cavity loop coupler assemblies (Fig. 6) were so designed, having the ability to vary the amount of coupling by rotation of the loop about its axis. Turning is accomplished manually with handles whose position, as defined by an imprinted scale on the coupler housing, indicates degrees of loop rotation. The full open position of the loop presents a coupling area of 5.2 square inches which may be varied to zero by turning the loop 90°.

Since the linac cavity is an extreme vacuum envelope, it was necessary for the loop assemblies to provide for vacuum-tight sealing of the ports. This is effected by one of the two teflon insulators positioning the inner coax. The insulator is made vacuum-tight by ¼-in.-diameter O-rings (Viton) seated in standard grooves. To prevent atmospheric pressure from dishing the insulator inward, mechanical support is given to it by the inner coax which anchors it to a plate capping the assembly. (The resultant Tee configuration was reproduced also in the design of the 8-in. transmission line fittings because of its having more favorable electrical characteristics than an El configuration.) A single row, deep-groove ball bearing is carried by the inner coax to permit the loop to rotate and at the same time transmit support to the insulator.

To minimize the torque required for rotating the loop, Viton rubber quad-rings specially treated by the manufacturer to have lower break-out and dynamic friction characteristics, were used for the rotary seal. The seal is formed by two ¼ in. X 8 in. ID rings in tandem. To further insure positive sealing, vacuum grease was forced in to fill a 1/32-in. undercut between the quad-rings.

Throughout the system, electrical contact between stationary parts is made with silver-plated, 1/8-in.-diameter spring rings and between moving parts with beryllium copper spring finger stock.

The output coupler of each TH515 power amplifier (Fig. 8) is also made variable, but in contrast to the linac cavity loops, coupling is changed by regulating the depth of penetration of a capacitor plate. Starting from a fully withdrawn position the plate has a throw of 3 in. inward.

To further facilitate tuning of the multiport system, each TH515 amplifier powering a loop is mounted on a carriage which enables it to be moved through a distance of ½ λ. A roller bearing cam follower is mounted at each corner of the amplifier which travels over a machined-surface bed. As part of this feature, both the 8-in. and 3-in. transmission lines are provided with telescoping sections (Fig. 9) where required. The mating lengths of these sections were made as thin walled as mechanically practical to minimize diameter step-down and hence impedance change. For the 8-in. line notably, the mating length of the outer coax was machined to have a wall of 1/16 in. In the installation of the amplifiers, transmission lines, etc., particular care was exercised in the positioning and alignment of the components to prevent binding of the telescoping sections during movement of the amplifiers. Final alignment of the transmission lines is preserved by stays and supports located where necessary.

Results

Figure 4 shows the variation of the tank pattern at $Z \approx 0$ under three different drive configurations. This is a representative observation point as it shows the superposition of the higher modes present. For the three port drive configuration, the faster rise time is due to overcoupling since the loops are set for a beam-loaded cavity. Another factor[9] in this rise time improvement is the operating frequency which is $f_o + \Delta f$. In addition, the rise time is also affected by the feed line length[9] which is adjustable. At the present time the normal linac output current is a 50 mA, 80 μs pulse (10 turn injection). For this current Δf was measured to be -1 kHz. Figure 5 displays several monitor wave shapes for this output current which is higher by a factor of two than our previous operating current. The observed half-width energy spread was 250 keV and is comparable to the one obtained with a 25 mA beam. As ion source development continues, it is expected that 75 mA will be accelerated in the near future.

Acknowledgements

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References

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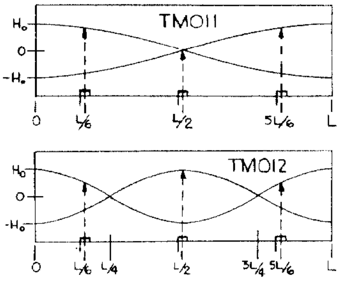


Fig. 1. H field distribution at cavity wall as a function of z for TM_{011} and TM_{012} modes.

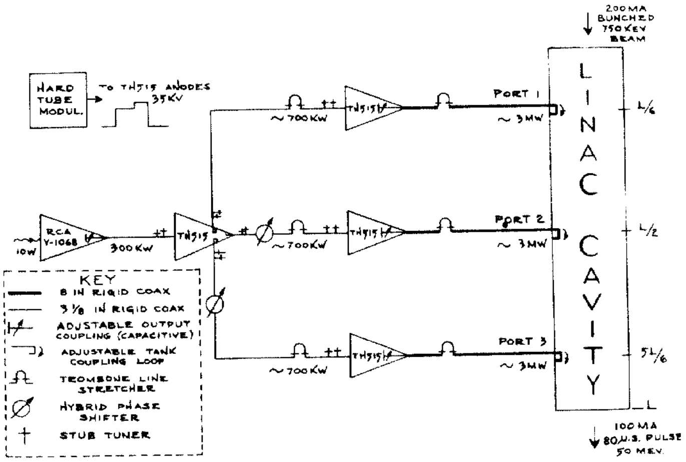
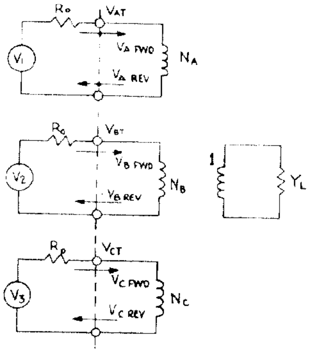


Fig. 2. High power RF system schematic.



$V_{1,2,3}$ = EQUIVALENT SINUSOIDAL GENERATORS DRIVING PORTS 1,2 AND 3

R_0 = GENERATOR CHARACTERISTIC IMPEDANCE

$N_{A,B,C}$ = EQUIVALENT TRANSFORMER TURNS RATIO

$V_{A,B,C}T$ = TERMINAL VOLTAGE AT TANK PORT

$V_{A,B,C}$FWD = INCIDENT VOLTAGE WAVE

$V_{A,B,C}$REV = REFLECTED VOLTAGE WAVE

Y_L = EQUIV. LOAD

P_B = POWER DELIVERED TO BEAM

P_T = POWER DELIVERED TO TANK

$\eta = \frac{P_B}{P_B + P_T}$

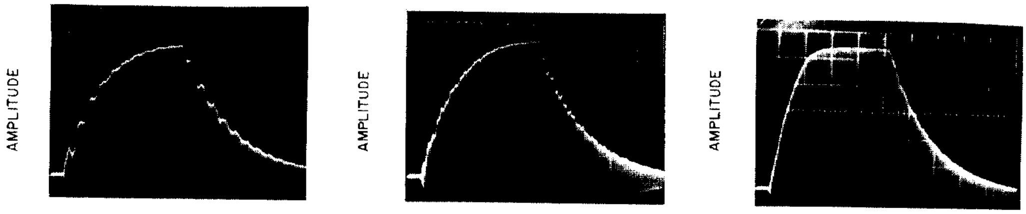
R_s = TANK LOSSES EQUIV. RESISTANCE

φ_s = PHASE ANGLE BETWEEN BUNCH CENTER OF MASS AND MAXIMUM R.F. TANK VOLTAGE

f_0 = UNLOADED TANK RESONANT FREQ.

Δf = FREQ. SHIFT REQUIRED TO RESONATE BEAM LOADED CAVITY

Fig. 3. Approximate equivalent circuit and symbol definitions.

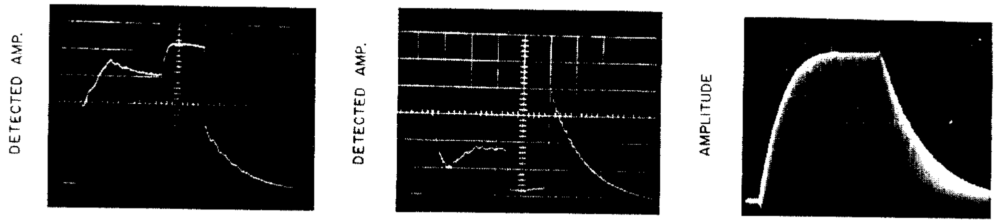


50 μs/DIV
SINGLE DRIVE AT Z=L/6

50 μs/DIV
SINGLE DRIVE AT Z=L/2

50 μs/DIV
TRIPLE DRIVES AT Z=L/6, L/2, 5L/6

Fig. 4. Tank patterns at Z = 0 for different driving configurations.



50 μs/DIV
$V_{C\,FWD}$

50 μs/DIV
$V_{C\,REV}$

50 μs/DIV
TANK PATTERN (Z=L/3)

Fig. 5. Some observed waveshapes for a 50 mA, 80 μs beam.

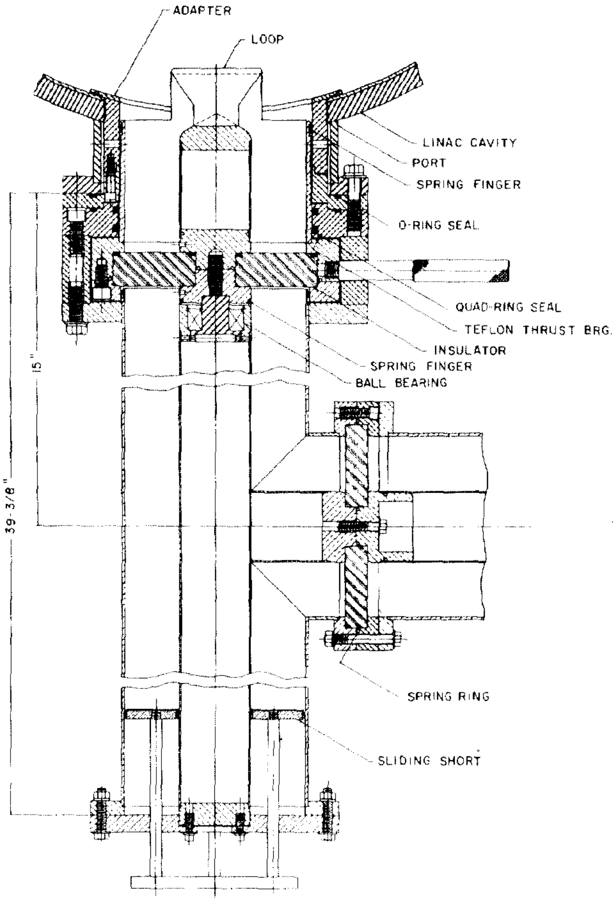


Fig. 6. Linac cavity variable coupler assembly.

Fig. 7. L/6 loop installation (low energy end looking downstream).

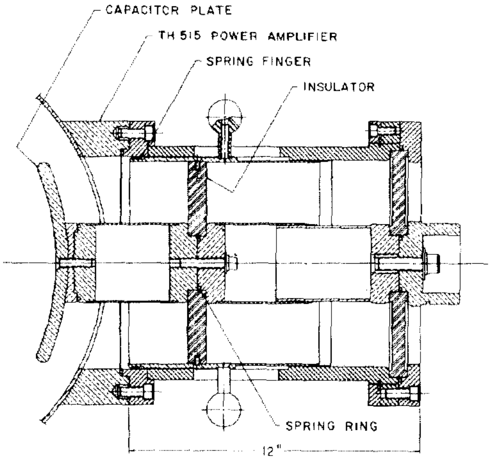


Fig. 8. TH515 power amplifier variable coupler assembly.

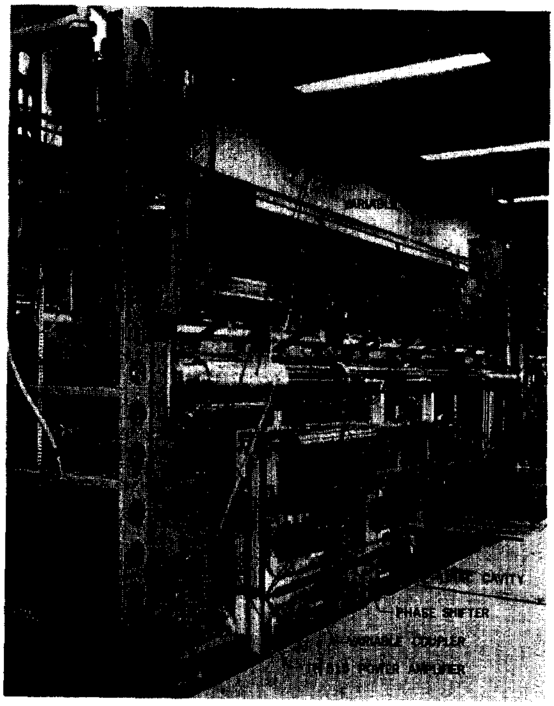


Fig. 9. L/2 loop installation (downstream view).