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RFQ AMPLITUDE FEEDBACK LOOP CONTROL

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I. INTRODUCTION

The existing Radio Frequency Quadrupole (RFQ) at LINAC is driven by an RCA 4616 tetrode. The operating frequency is 201.25 MHz and the peak output power is approximately 100KW. The screen voltage of the 4616 is used to control its output RF power. The screen voltage is a 1ms-wide pulse with an amplitude of 1,700V. The pulse rate is one pulse per 2.2 sec. The 4616 screen voltage is provided by a cathode follower type modulator whose output stage is an Eimac 4cx1000A tetrode.

Circuitry has been developed to provide closed loop control of the RFQ magnetic field amplitude using a modified version of the existing 4616 screen modulator. The redesign was undertaken to reduce pulse to pulse variations and pulse drop in the RFQ accelerating field to less than 0.1%.

II. SOME CONSIDERATIONS

The configuration of the RF amplitude feedback loop system is shown in Fig. 1.

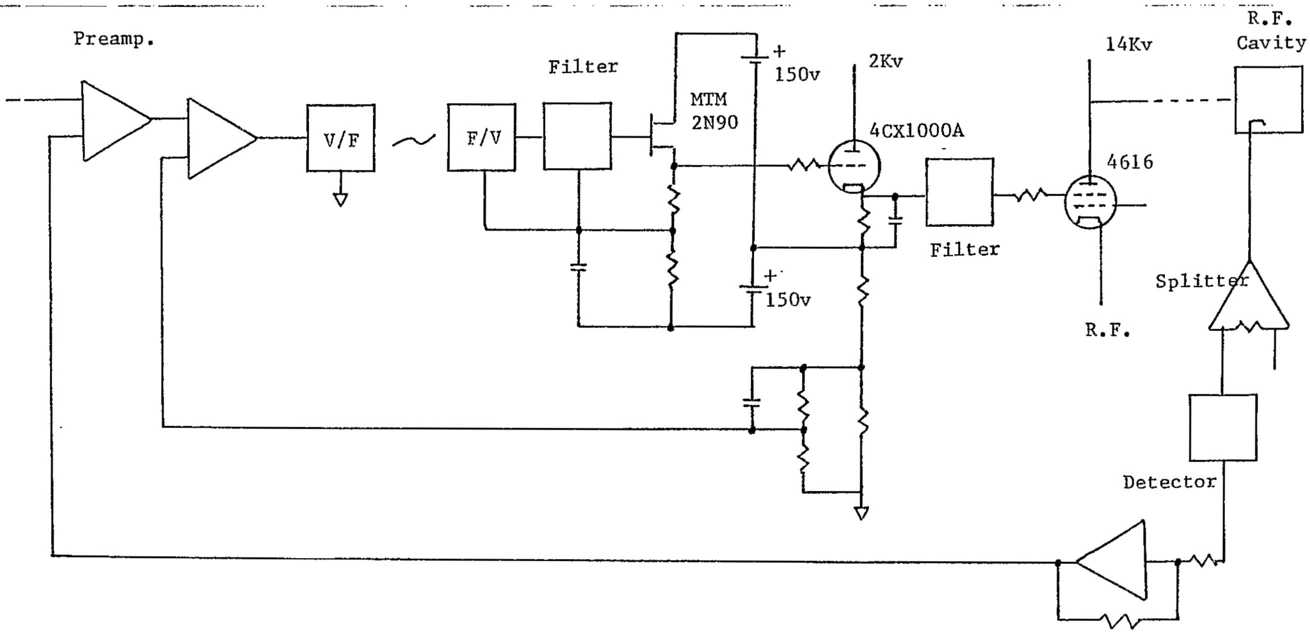

Fig.1

A few system considerations are as follows:

i, Since the RF amplitude in the cavity is controlled by a feedback servo-system, some overshoot is unavoidable. Too much power will cause the cavity to break down. The maximum breakdown power limit is approximately 140KW and the overshoot must be limited accordingly. The 4cx1000A anode voltage is 2KV, which is close to the maximum tube rating. However, in order to drive the 4616 screen, the cathode voltage of the 4cx1000A should be about 1,700V, which means the tube is working near saturation. Hence, the system is not a small signal system, and there is a considerable nonlinearity.

ii, The specific structure of 4616 shows that there is an 18,000 pF RF by-pass capacitance between the screen and the cathode. Therefore, we used a cathode-follower type circuit as the screen driver for the 4616 because of low output impedance required. The amplifier that drives the 4cx1000A grid then must float at 2KV, the maximum 4cx1000A cathode voltage. The input to this floating amplifier must cross a 2KV interface and the solution chosen was a fiber optic link using V/F converter. The rate of rise of the 4cx1000A cathode voltage is greater than 1KV/μ second. This condition precluded the use of standard opto isolators.

iii, Some RF leakage is present at the 4616 grid. This 201.25 MH_z signal must be filtered so that it does not interfere with proper closed loop control.

The network connected between the cathode of 4cx1000A and the screen of 4616 is as follows:

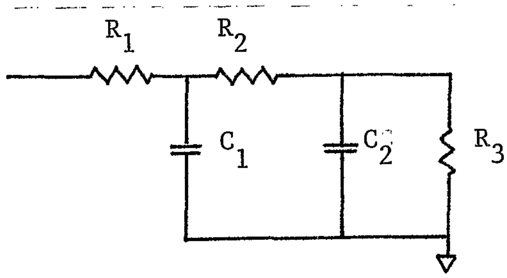

Fig.2

where $R_1 = 350\Omega$, $R_2 = 250\Omega$, and $C_1 = 6{,}000$pf.

C_2 is the 4616 screen capacitance (18,000 pF).

R_3 is the dynamic resistance between screen and cathode of 4616, which is in the range of 5K - 15K and can be neglected. Thus, the transfer function of this network is

$$\frac{10^{11}}{s^2 + 12 \times 10^5 s + 10^{11}} = \frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2}$$

Computation shows that the major time constant is

$$\tau = 12 \ \mu\text{sec.}$$

iv, A FET (MTM2N90) was chosen as the driver for the 4cx1000A. The maximum power dissipation is 75W, and VDG max is 900V. The ±150V power supplies are referenced to the cathode of 4cx1000A. Local source current feedback is provided by a 100 Ω resistor. During the pulse period, the Drain potential approaches 1,900V and the leakage capacitance between the primary and secondary windings of the power transformer which provides ± 15V for the F/V converter, induces a high voltage transient across the Drain and Gate of MTM2N90, which can cause FET failure. This problem has been solved by adding another 1 : 1 isolating power transformer between these transformers and the power supply network.

v, The RF cavity can be modeled as a parallel RLC network with resonant frequency at 201.25MHz and Q value of approximately 5,000, and it's second order transfer function is:

$$\frac{\frac{1}{C} s}{s^2 + \frac{1}{RC} s + \frac{1}{LC}}$$

From $$2\zeta\omega = \frac{1}{RC} = \frac{\omega}{Q}$$

We have

$$\zeta = \frac{1}{2Q} = 10^{-4} < 1$$

The envelope time constant is

$$(\zeta \omega)^{-1} = (10^{-4} \times 2\pi \times 2 \times 10^{8})^{-1} = 7.96 \ \mu\text{sec}.$$

vi, A Hewlett Packard fiber optic system is used with a Burr Brown VFC62CG converter with a range from 0 - 2MHz. Probably the most important part is the F/V converter, which is, in principle, a low pass filter constructed as follows:

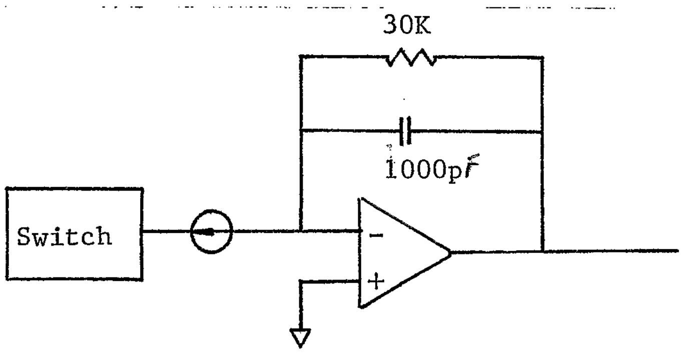

Fig.3

In the full scale input case, the duty ratio is about 0.5. The RC constant is 3×10^{-5} sec. Thus, the following model (disregarding the gain) is used to simulate the converter

$$\frac{1}{1 + 6 \times 10^{-5}s}$$

i.e., there is a 60 µsec. time constant.

In order to further reduce the F/V ripple content we added another low pass filter following the F/V converter, as follows:

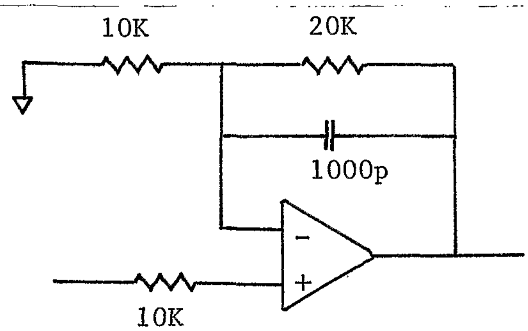

Fig.4

The transfer function is:

$$3x \; \frac{1 + 7 \times 10^{-6}s}{1 + 2 \times 10^{-5}s}$$

vii, In Comparison with the filter following the 4cx1000A cathode and the RF cavity, the F/V converter and its associated filter dominate. Local feedback from the cathode of the 4cx1000A was designed to stabilize the whole system. It is as follows:

$$\frac{1}{101} \times \frac{1 + 4.25 \times 10^{-4}s}{1 + 4.25 \times 10^{-6}s}$$

viii, We choose unity feedback to close the loop. The feedback signal is picked up from a detector following a splitter, which is driven from an H field probe in the cavity wall. A follower is used to transmit the signal from the detector to the preamplifier. We found that a follower built with μA741, with a 2 MH_z bandwidth lead to instability. An LF356, with a 5MH_z bandwidth eliminated the difficulty.

III. SIMULATION

The following diagram is the simplified system model.

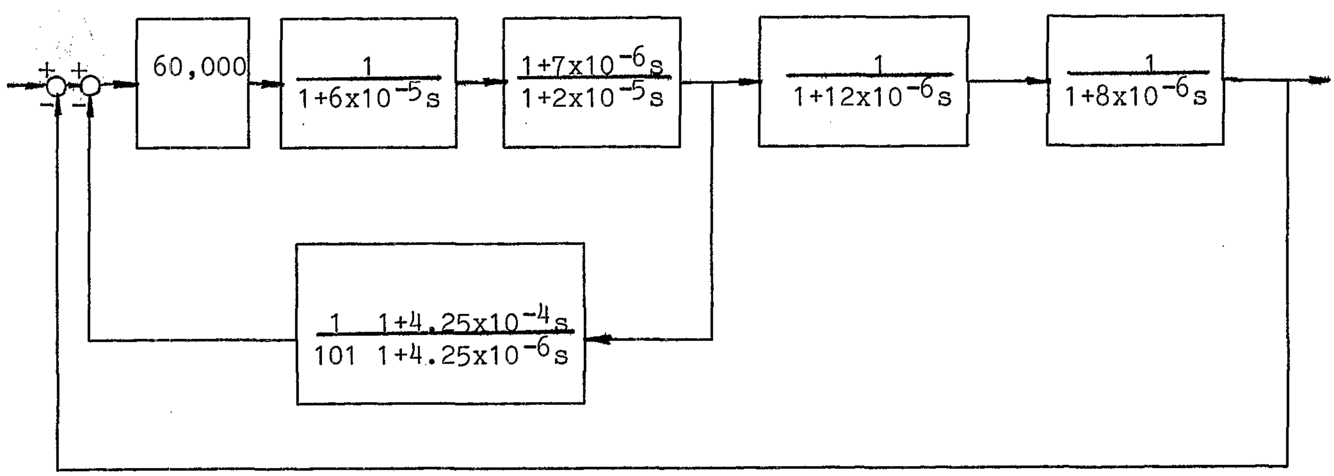

Figure 5

The converter, its filter, and the local compensation models are taken directly from (vi) and (vii) of last section. The R. F. filter discussed in (iii) is reduced to a one-order delay system with 12μs time constant, while the RFQ cavity is modeled by an 8 μs time constant delay system. The gain from input to the output of the screen modulator is roughly 60,000. The open-loop transfer function of the whole system is

$$G_o(s) = \frac{1785s^2+6.75\times10^8 s+6\times10^{13}}{4.896\times10^{-16}s^5+1.716\times10^{-7}s^4+6.063\times10^{-2}s^3+7030s^2+2.713\times10^8 s+6.01\times10^{11}}$$

The Bode plot of Go(s) is shown in Fig. 6, where it is shown that the gain margin and phase margin of the system are 15 db and 20°, respectively. The gain

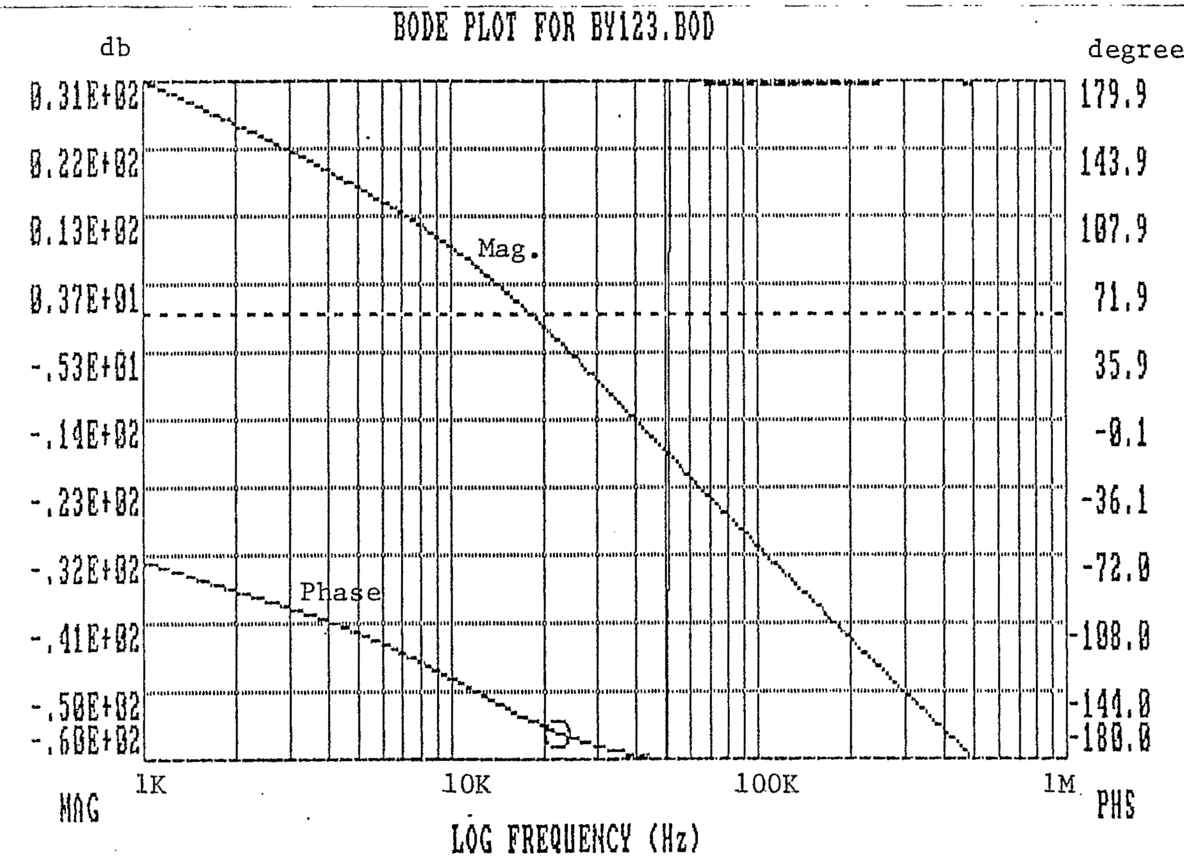

Fig. 6

The closed-loop transfer function is computed as

$$G_f(s) = \frac{1785s^2+6.75\times10^8 s+6\times10^{13}}{4.896\times10^{-16}s^5+1.716\times10^{-7}s^4+0.0606s^3+8815s^2+9.463\times10^8 s+6.06\times10^{13}}$$

The time response for a step input is shown in Fig. 7. As explained in (i) of section II, the overshoot of 50% in Fig. 7 is excessive. To avoid cavity breakdown we used a rounded front-edge step reference signal to lower the overshoot.

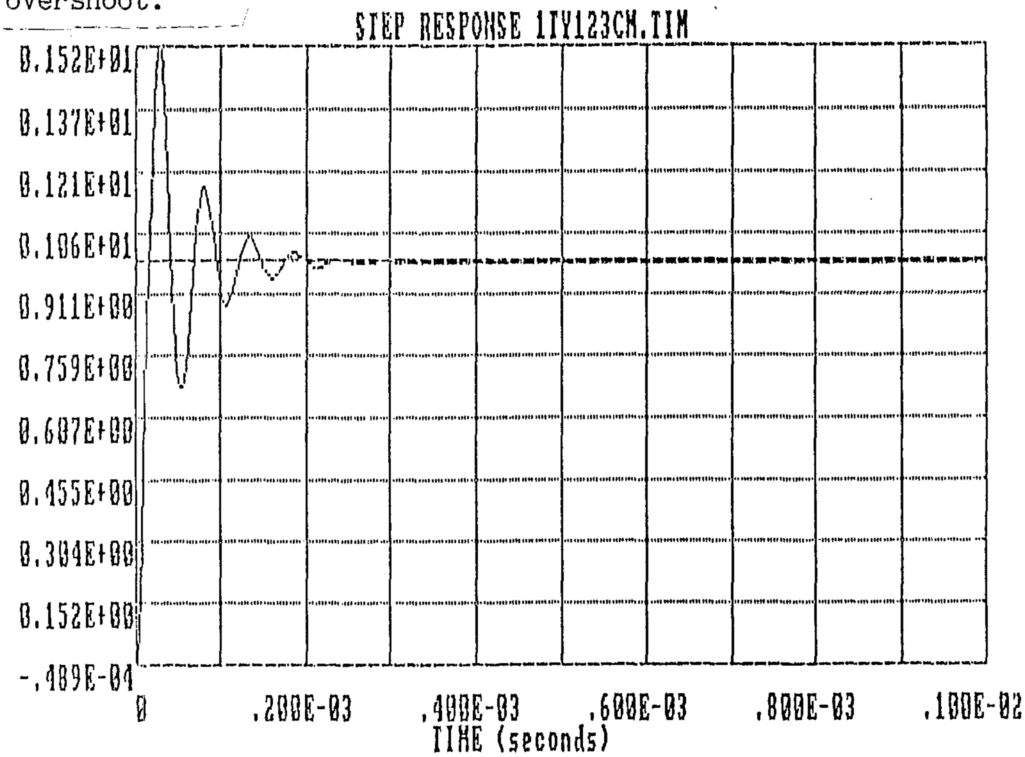

Fig. 7

All the simulations were conducted using the CONSAP circuit analysis program on an IBM PC-XT.

IV. PERFORMANCE

Figure 8 shows an oscillograph of the detected H field at the cavity wall without amplitude control. The oscillograph in Fig. 9 shows the same detected signal with the loop closed. The overshoot is about 12%. The rise time is about 40μsec. The loop gain is about 70. When the anode voltage of 4616 changes from 12KV to 16KV, the RF power in the RFQ changes less than 0.1%. Note that the performance shown in Fig. 8 is quite similar to the simulation result of Fig. 7.

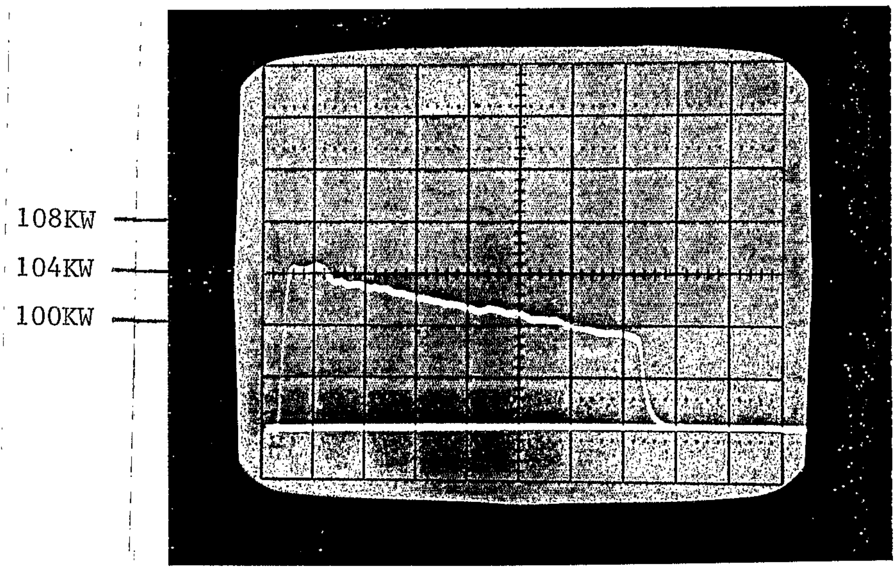

Fig.8

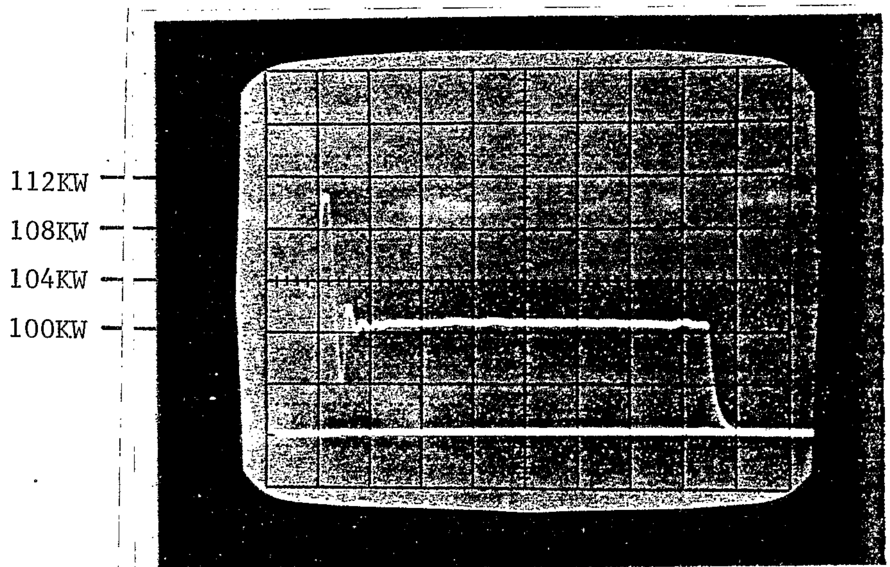

Fig.9