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A PROPOSED RF SYSTEM FOR THE FUSION MATERIALS IRRADIATION TEST FACILITY*

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Abstract

Preliminary rf system design for the accelerator portion of the Fusion Materials Irradiation Test (FMIT) Facility is in progress. The 35-MeV, 100-mA, cw deuteron beam will require 6.3 MW rf power at 80 MHz. Initial testing indicates the EIMAC 8973 tetrode is the most suitable final amplifier tube for each of a series of 15 amplifier chains operating at 0.5-MW output. To satisfy the beam dynamics requirements for particle acceleration and to minimize beam spill, each amplifier output must be controlled to $\pm 1^{\circ}$ in phase and the field amplitude in the tanks must be held within a 1% tolerance. These tolerances put stringent demands on the rf phase and amplitude control system.

General Description

Preliminary rf system design for the linear accelerator (linac) portion of the FMIT facility is in progress.[1] The 35-MeV accelerating structure will consist of a low-beta radio-frequency quadrupole (RFQ) accelerator/buncher[2] up to 2 MeV and two post-coupled Alvarez tanks in series, with an intertank spacer at the 20-MeV point. The 35-MeV, 100-mA cw deuteron beam will require approximately 6.3-MW rf power at 80 MHz.

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The basic layout of the FMIT rf system is illustrated in Fig. 1. Each rf amplifier chain will generate at least 500-kW of power. The RFQ will require two amplifier chains and each linac tank will need at least six or seven. A multiplicity of drive loops will be used for inductively coupling the rf into the accelerator tanks. Each power amplifier (PA) will have its own coupling loop. To obtain optimum particle acceleration and to minimize beam spill, beam dynamics requires that the accelerator fields be controlled to $\pm 1^{\circ}$ in phase. Also, the field amplitude in the tanks must be held within a 1% tolerance. These requirements place stringent demands on the phase and amplitude control systems.

High Power Amplifiers

Amplification from 100 W to 500 kW will be accomplished by several stages of vacuum tube amplifiers. The tube selected for the final amplifier is the EIMAC 8973 (formerly X-2170) power tetrode. The Los Alamos Scientific Laboratory (LASL), in cooperation with EIMAC, has embarked on a test program to determine the capabilities of the 8973 tetrode. The tube has been operated in the grounded-grid grounded-screen configuration at 80 MHz for over 6-1/2 hours at a 525-kW rf output. The tube had a 14-db power gain, which was slightly higher than the calculated gain of 12 db, because in this configuration it was behaving more like a high-μ triode than a tetrode. The most vulnerable tube element is believed to be the screen grid. Because of the high plate to screen capacitance (~140pF), rf displacement current heating of the screen structure becomes significant at frequencies above 50 MHz. Because of the very low thermal capacity of the screen structure, this element should reach

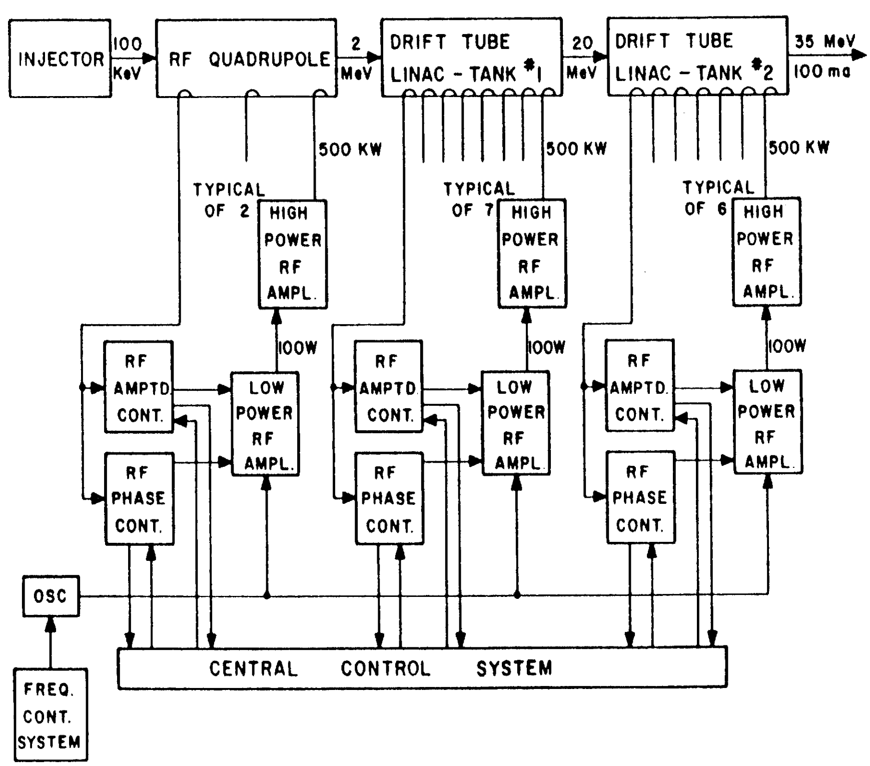

Fig. 1. The FMIT rf system.

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a stable temperature in just a few minutes of operation. Consequently, if the screen doesn't fail within several minutes of operation, it will probably survive indefinitely. On the other hand, the ceramic tube seals are more prone to deterioration over a long period of time but seal integrity is more dependent on the larger dissipations of the filament and the anode, which in all cases were running within or well below maximum ratings. The maximum output of the 8973 has not been determined yet because of output cavity arcing at the 550-kW level and a lack of sufficient drive power.

Drive modulation tests up to 300 kW exhibited a reasonably linear response. There was no evidence of discontinuities in gain and no spurious components could be detected in the 8973 output under several conditions of drive modulation.

Low Power rf

The low-power rf stage will supply an rf signal of the proper frequency, phase, and amplitude (0-100 W) to drive the PA such that the PA output is also at the required frequency, phase, and amplitude (0-500 kW) for optimum accelerator performance.

The accelerating field is the vector sum of the rf fields produced by the energy delivered to each tank by several rf power amplifiers. Feedback control loops around each PA and around each accelerator tank insure that the field in the tank remains at the correct phase and amplitude with or without beam. The phase and amplitude controlling takes place at the 1-W level. The rf drives for all three tanks are essentially the same so only one amplifier chain will be described in detail. Figure 2 contains the block diagram for one complete rf amplifier chain including feedback control loops.

The tank resonant frequency is critically temperature dependent. When the tank is cold, as in start up, the resonant frequency could be as far as 1.5 MHz from 80 MHz and the bandwidth of the tank is so narrow (~3 kHz) that the 80-MHz amplifiers cannot drive energy into it. The frequency control system is designed to find, lock on, and track the linac resonance so that the tank can be heated with rf energy. In the search mode the rf source is switched to a voltage controlled oscillator (VCO), which generates 1-ms pulses with a pulse repetition frequency of 120. The VCO shifts about one tank bandwidth on each pulse. When a feedback signal from a pick-up loop in the tank indicates power flow into the tank, the VCO locks onto that frequency and tracks it as the tank warms up to normal operating temperature. At this time the VCO is switched out and is replaced with a crystal oscillator with an 80-MHz output for normal operation.

The central control system (CCS) generates an amplitude set-point signal proportional to the desired field level in the accelerator tank. This set point is also proportional to the average output power required of each rf amplifier chain to achieve the desired tank field. This set point is distributed to the amplitude control circuit of each PA. Coupling loops in the accelerator sample the field amplitude in several places. These sample signals are detected and summed to generate a tank feedback signal that is proportional to the average rf field in the tank. The tank amplitude set-point signal is subtracted from the tank feedback signal to generate a control signal proportional to their difference (error). This tank amplitude control signal is distributed to the amplitude control circuit of each PA.

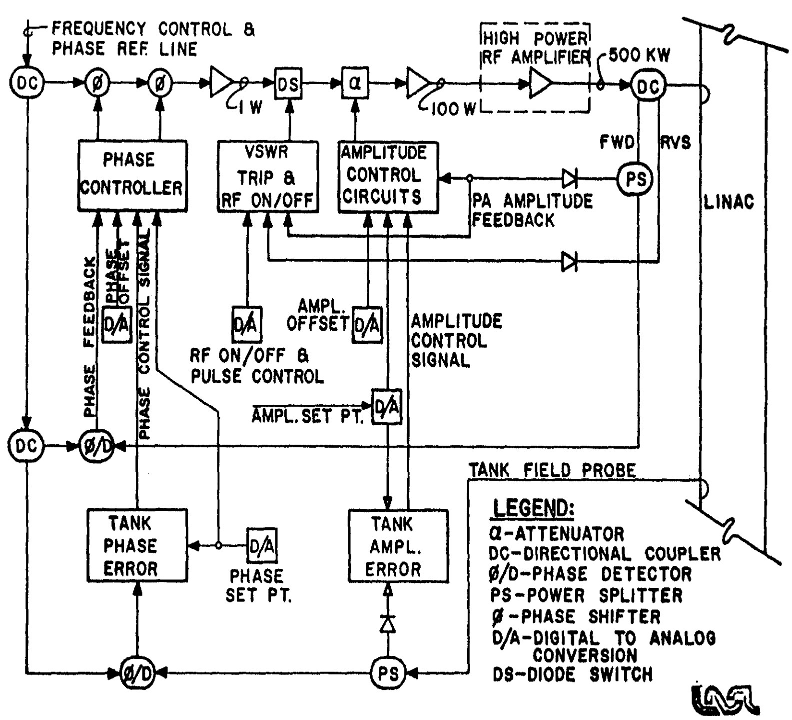

Fig. 2. A single rf amplifier chain.

In normal operation each PA will deliver its equal share of the required power. Under some conditions a PA will operate at a higher or lower output power level. The CCS may generate on "offset" signal for some drive chains to increase or decrease their output power.

The amplitude control circuit of each PA receives four control signals:

1. Amplitude set point, proportional to the average power output of each PA.

2. Amplitude offset, proportional to the difference between actual power output of a PA and average power output of all PAs.

3. Tank amplitude control, proportional to the difference in the actual tank field and the tank amplitude set point.

4. PA amplitude feedback, proportional to the PA power output.

Signals 1, 2, and 3 are combined to generate an "effective set point" for each PA. This signal is compared with the PA amplitude feedback (4 above) to generate a control signal for the voltage variable attenuator that controls the overall gain of the rf amplifier chain.

When beam is injected, the heavy beam loading causes field droop in the accelerator. The tank amplitude control signal increases, which changes the "effective set point" for each PA. This change increases the power gain of each PA causing the average field level in the accelerator to maintain its desired value.

The phase control system is quite similar to the amplitude control system. The phase control system consists of four parts: phase detector, phase controller, $\pm 45^{\circ}$ varactor-tuned electronic phase shifter, and a PIN diode digital phase shifter with a 360° range in 45° increments. These four parts are shown in Fig. 2. The 80-MHz oscillator acts as the phase reference for the phase control system.

The CCS generates a phase set point that is proportional to the desired rf field phase in the tank and also proportional to the PA output with respect to the phase reference. This set point is compared with the actual detected tank phase and a phase control signal (error signal) is generated and distributed to each phase controller. The phase set point, the phase control signal, and CCS generated phase off-set signal are all inputs to the phase controller of each PA. A phase feedback signal that is proportional to the difference between the reference phase and the PA output phase is also a phase controller input. Because the phase shift through the PA changes with output power, this controller input assures a constant PA output phase under all operating conditions.

The phase controller generates an output signal that tunes the varactor phase shifter to produce the required phase shift. The digital phase shifter is adjusted to keep the varactor phase shifter within its operating range.

Prototype

A prototype FMIT accelerator capable of producing 5-MeV H_2^+ particles is under development now at LASL. This accelerator will require four rf amplifier chains to supply the necessary energy for beam acceleration. The prototype rf system used at LASL will prove the final design for the FMIT accelerator to be built at the Hanford Engineering Development Laboratory in Richland, Washington.

References

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