THE RACETRACK MICROTRON RADIO-FREQUENCY SYSTEM

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Summary

The design and construction progress of a prototype rf system to drive the Los Alamos-NBS racetrack microtron (RTM) electron accelerator is described. The rf system requires 450-kW cw at 2380 MHz from a single klystron. The output from the klystron is split three ways to drive a capture section, a preaccelerator section, and the main accelerator section. The fields in each section are phase- and amplitude-controlled to tight tolerances. Temperature control of the accelerator sections also is linked to the amplitude-control system, because the system's average power is so high.

Introduction

The overall accelerator is reviewed in Ref. 1, and the rf system is shown schematically in Figs. 1 and 2. The beam goes from a 100-kV injector, through a pair of TM_{110} chopper cavities, then through a buncher cavity. There is a 2.4-m preaccelerator section and a 1-m capture section in the injection line, and the main acceleration section on the RTM is 8 m long. All three accelerator sections are designed for 1.5 MeV/m and are of the disk-and-washer type described in in Ref. 2. The TM_{110} modes and fields in the square chopper cavities are independent of each other. Thus, a total of eight rf fields must be controlled in amplitude and phase for the system to operate. Three 75-W amplifiers and one 450-kW klystron, aided by four variable-ratio power dividers[3] and four high-power phase shifters constitute the high-power rf system. Normally the rf system is operated

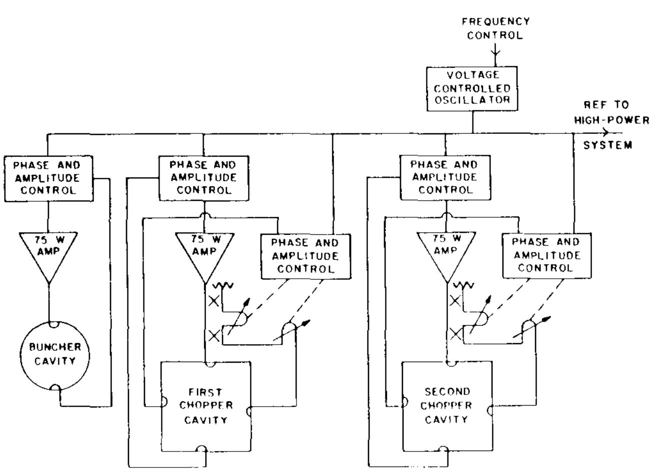

Fig. 1. Low-level rf system schematic.

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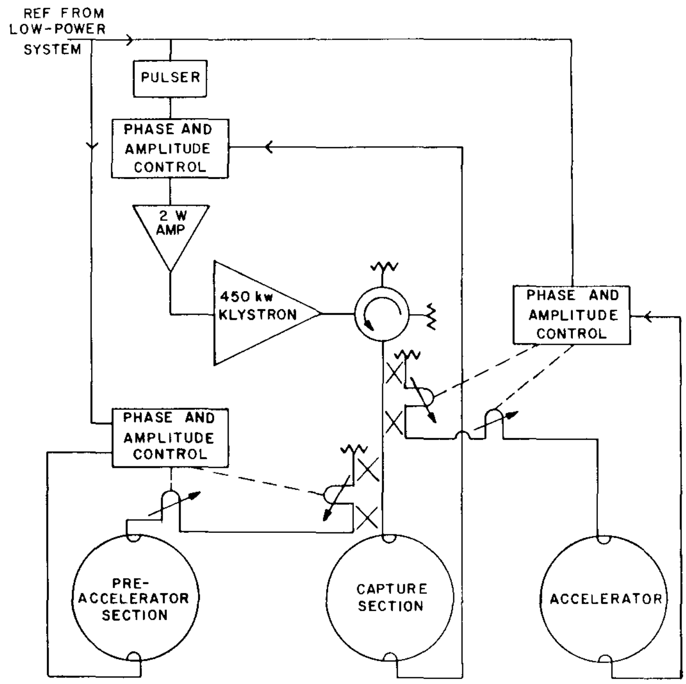

Fig. 2. High-power rf system schematic.

cw, but the klystron drive may be pulsed to facilitate conditioning of the high-power cavities. The rf system comprises the following subsystems: the low-level rf system, the dc power supply, the waveguide power-distribution system, the klystron, the phase- and amplitude-control system, the water-cooling system, and the safety-interlock system. The major design parameters and problems associated with each system are discussed, and the overall progress to date is reviewed.

The Low-Level rf System

The rf source is a voltage-controlled crystal oscillator (VCXO), followed by a 16-times multiplier with a 2380-MHz output frequency. The oscillator may be electrically tuned by ±2.4 MHz. The rf source also includes a 1-W amplifier and an 8-way power splitter. Thus, about 100 mW of power are available at each of the eight outputs. The line to the klystron driver has a 1-kHz, 50- to 500-μs gate that is controlled by an analog signal from the computer. Once a cavity can tolerate 50% duty factor, the gate module remains "on" and the klystron operates cw. Prototypes of the gate and source modules have been built and tested at Los Alamos.

The turn-on problem is one of the most difficult in the rf system. The washers will be warmed up by 15°C by the rf fields, and the cavities will change resonance frequencies by about 25 kHz/°C. During cold weather, the inlet water temperature will be low at times when no rf power is being applied; but once the system is operating, the inlet water temperature may be as high as 35°C. The sensitivity of the cavity to changes in water-system temperature is 40 kHz/°C. Thus, its worst-case frequency change will be about 1775 kHz, which is well within the 2.4-MHz tuning range of the VCXO. Initially the computer will sweep the VCXO to find the cold resonance frequency, with low power delivered to the cavities. Then the power will be increased, and the frequency will follow the cavity resonance as the cavity and the water system become warmer. A mechanical tuner has been designed as a back-up system, but evidence so far indicates that the VCXO tuning method alone will be adequate.

There are three gridded-tube 75-W amplifiers and feedback loops (Fig. 1) that are used to drive the buncher and the two chopper cavities; these amplifiers have 20-dB gain. The three amplifiers and a spare all have been delivered and tested for several hours at full power.

The dc Power Supply

The dc power supply consists of four outdoor units: a fused manual circuit breaker, a vacuum circuit breaker, a linear variable transformer, and the transformer-rectifier unit. The input voltage is 13.2 kV at 52 A, three-phase. The output is 65 kV at 16.5 A, with less than 1% peak-to-peak ripple. The high-voltage transformer has a delta primary, and both delta and wye secondaries to reduce the ripple. The high-voltage transformer, the rectifier stacks, and a one-stage LC filter are all housed in a common oil tank. An ignitron crowbar and its dropping resistors are housed indoors. Neither side of the power supply is solidly grounded, and a single-point ground is established at the crowbar unit. The crowbar fires within 5 μs of a fault, and the vacuum circuit breaker can open in 30 ms.

The linear variable transformer is motor driven, and the output voltage is continuously adjustable from 33 kV to 65 kV. The power supply is now completely installed at Los Alamos and has been tested to full voltage and current. A foil tester has been added to the crowbar, but the crowbar unit has not yet passed this test. We expect the power-supply to be completely operational by November 1, 1981.

The rf Power-Distribution System

The 450-kW cw rf power from the klystrons will be delivered to the main accelerator and the preaccelerator and capture sections. The phase and amplitude in each of these cavities must be controlled independently. The system uses a WR-430 waveguide that is water cooled for phase stability. A schematic of the system is shown in Fig. 2. The use of a circulator at this very high power level would not be required if the waveguide length between the cavities and the generator were constant, but the variable-ratio power divider changes this length as the ratio changes. Thus, the klystron may see a high load impedance, which can damage the klystron. The klystron could have been designed to operate stably into a higher mismatch, but this design would lower the overall efficiency for the matched condition. Therefore, a high-power circulator has been ordered, but it is uncertain that the circulator is necessary for different methods of distributing the rf power. The phase shifters and power dividers in Fig. 2 all are controlled by stepper motors and feedback systems. All waveguide components, except the circulator, have been delivered to Los Alamos; the circulator is scheduled for delivery in February 1982. Thus, the initial cavity tests will be performed without a circulator; but the klystron will be protected by VSWR detectors, arc detectors, and the body-current protection circuit.

The two TM_{110} chopper fields in each chopper cavity are derived through a variable-ratio power divider and phase-shift system that are coaxial, rather than waveguide, components. A single 3 dB hybrid would suffice if the coupling loops and all other physical attributes of the two modes were identical; but the actual method used will have to be very tolerant of asymmetry in the system.

Klystron

The klystron to be used is a VKS-8270 klystron that has five fixed-tuned cavities. The tube is rated 450 kW cw at 2380 MHz. The collector is dc-isolated from the klystron body, so that the body current may be easily monitored. Two complete amplifier packages, each consisting of a klystron, solenoid, and socket tank, have been ordered and now are at Los Alamos. In their factory tests, both tubes delivered 500 kW, had 57-dB gain, and ±20-MHz bandwidth. One complete klystron amplifier is set up at Los Alamos and will be tested in early November, this year.

Phase and Amplitude Control System

The phase- and amplitude-control system achieves control by electronic and mechanical methods. The buncher control loop is an exception: It has only electronically controlled phase shifters and attenuators. The chopper cavities have a mechanically controlled, variable-ratio power divider and phase shifter; these control the amplitude and phase of the second field, while the electronic loop controls the primary field variables. The electronic control on the klystron system controls the field in the capture section, and two waveguide variable-ratio power dividers and phase shifters are used to control the fields in the preaccelerator and main accelerator tank. Rapid beam-loading transients will be avoided, and the slow mechanical system keeps the average errors in tuning temperature under control.

Water Cooling System

The total water-system requirements are 390 gpm at 65 psi of deionized water; the waveguide cooling system requires 5 gpm at 30 psi of tap water. A schematic of the deionized water system is shown in Fig. 3. The accelerator cavities require up to 320 gpm, but these have their own pumps and deposit heat only into the main water system. The temperature of the accelerator cavities must be controlled to ±0.5°C; this control will be accomplished by a three-way mixer valve. The klystron and water loads are quite tolerant to water temperature, but the circulator requires ±2°C input water; thus it is also on an auxiliary loop, connected to the main water system by a three-way mixer valve.

Safety-Interlock System

A Kirk-key system is used on the 65-kV dc power supply to prevent personnel access to the input and output of this supply. The rf waveguide distribution system has a single air inlet and outlet. The inlet is pressurized with a small blower, and a moving-air detector is used at the output to ensure that there are no openings in the waveguide system.

The ignitron crowbar is activated by the rate of rise of the klystron cathode current. When the crowbar fires or misfires, it is automatically reset by the computer, but if a second crowbar occurs within 1 min, it shuts down the entire system.

The minor faults in the rf system (bursts of body current, a waveguide arc, excessive reflected power to any cavity, excessive control-loop error signals) cause the rf drive to be removed from the klystron. After 1 ms, a lesser rf drive is reapplied. One such fault per second is allowed, but if 10/min occur, the system is shut down.

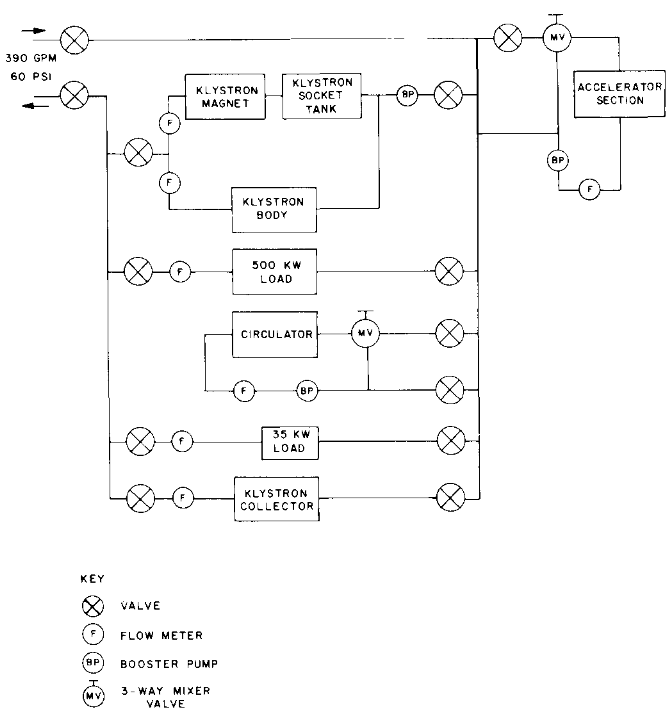

Fig. 3. Line diagram of water-cooling system.

The major faults usually involve a diminished water flow or excessive temperature. Thus, manual control of the water system is required. The klystron drive is removed and the 65-kV power supply is shut down. Other major faults include excessive klystron average-body current, klystron filament or magnet current being out of range, and high voltages or klystron vacuum too high.

Whenever any fault is detected, a signal is sent to the injector to shut off the beam injected into the accelerator. The beam is not turned on until the rf system has stabilized.

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