A RACETRACK MICROTRON RF SYSTEM*

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Summary

The rf system for the National Bureau of Standards (NBS)/Los Alamos cw racetrack microtron is described. The low-power portion consists of five 75-W amplifiers that drive two input ports in each of two chopper deflection cavities and one port in the prebuncher cavity. A single 500-kW klystron drives four separate 2380-MHz cavity sections: the two main accelerator sections, a capture section, and a preaccelerator section. The phases and amplitudes in all cavities are controlled by electronic or electromechanical controls. The 1-MW klystron power supply and crowbar system were purchased as a unit; several modifications are described that improve power-supply performance. The entire rf system has been tested and shipped to the NBS, and the chopper-buncher system has been operated with beam at the NBS.

Introduction

The NBS/Los Alamos cw racetrack microtron rf system consists of a low-power triode rf system and a high-power klystron system. The accelerator described in Ref. 1, has two major rf subsystems shown in Figs. 1 and 2. An electron beam from a 100-kV injector passes through a pair of TM_{110} chopper cavities, then is bunched in a single-cavity buncher. These three cavities comprise the low-level rf system; five 75-W triode amplifiers drive these cavities, as shown in Fig. 1. The beam next passes through a 1-m capture section, a 2.4-m preaccelerator section, and is injected into the microtron that has two 4-m main accelerating sections. These four accelerating sections constitute the high-power rf system, and all are driven by a single 500-kW klystron. The entire rf system operates at 2380 MHz and normally is operated cw; however, a pulser may be used in the high-power system to pulse the klystron drive for conditioning and tune-up of the accelerator. The dc power supply that drives the klystron has been modified as discussed in this paper. The waveguide power-distribution, water-cooling, and safety-interlock systems have been described in a previous paper[2] and are only briefly discussed here. The feedback control system is the subject of another paper.[3]

The Low-Level rf System

The low-level rf source is a phase-locked, voltage-controlled crystal oscillator. A stabilizing cavity and phase-lock circuit was added to the oscillator because the phase noise was too large without the cavity. The 75-W triode amplifiers required frequent retuning to maintain 75-W output capability. The original plan was to drive both TM_{110} modes with a single amplifier, but this required frequent adjustments of the amplifiers because the triodes were operated beyond the manufacturer's ratings. Therefore, two extra 75-W amplifiers were purchased, and adjustments were no longer required, because each mode only needed 30 W for attaining design rf fields in the cavities. The 75-W amplifiers had only two triode stages and fairly low gain; hence, each was preceded by a 30-dB-gain solid-state amplifier. The system, as shown in Fig. 1, has operated at design fields for several weeks at Los Alamos, and has operated well with beam at the NBS.

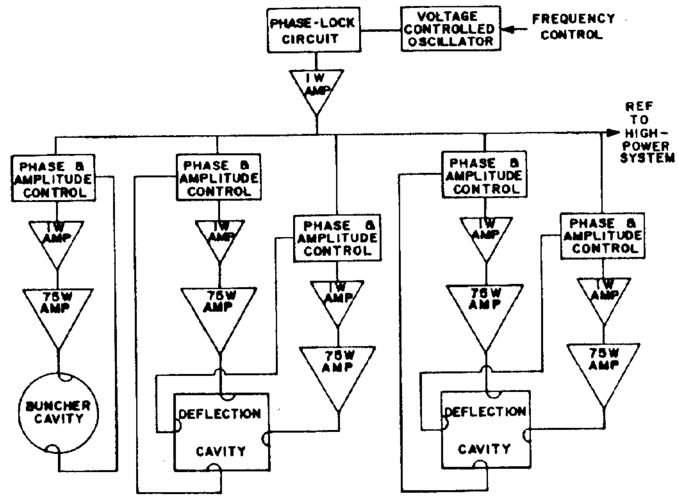

Fig. 1. The low-level rf system. The phase and amplitude controls are all electronic.

The High-Power rf System

The high-power rf system consists of a single 500-kW cw klystron that drives four separate accelerator sections (Fig. 2). The power is distributed through WR-430 waveguide that is water cooled for phase stability and for keeping the temperature at safe levels. Variable ratio power dividers[4] and waveguide phase shifters control the phase and amplitude in the accelerator sections. A 500-kW four-port circulator protects the klystron from reflected power. The klystron is a Varian VKS-8270, five-cavity, permanently-tuned klystron that has been operated at 500-kW cw at the factory and at Los Alamos. The klystron has a 57-dB gain; thus, it takes only 1 W to saturate. The klystron has been shipped to NBS and has been operated to 240 kW.

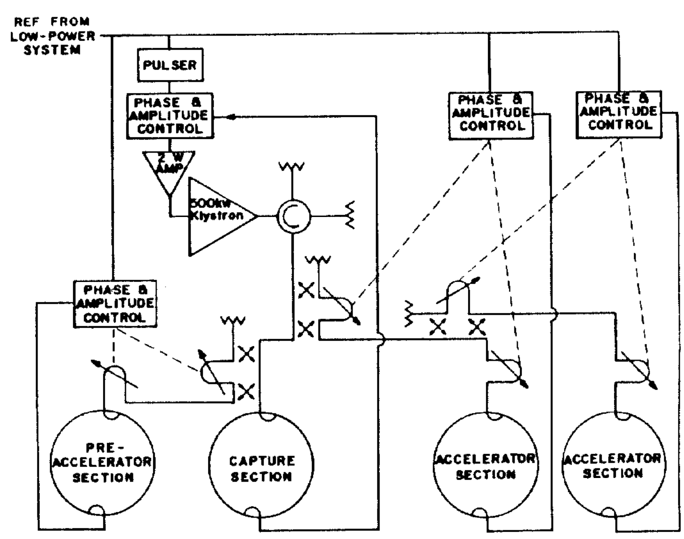

Fig. 2. The high-power rf system. The phase and amplitude controls are electronic for the capture section, and mechanical for the other three sections.

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The dc Power System

The dc power supply was purchased to provide the 65 kV and 16.5 A required to drive the klystron with a 1% voltage ripple specification. The dc voltage ripple initially was over 10% at full load, and the trouble was traced to the linear variable transformer that precedes the transformer/rectifier. This variable transformer was wound on an "E" core, with equal turns on the center and outside legs of the three-phase circuit. The self and mutual inductances of the center leg were different from that of the outside legs, and the voltage to the transformer became unbalanced. Because the transformer-rectifier has both wye and delta secondaries, the filter was designed for 720-Hz ripple; however, the unbalance (because of the different inductances) caused a 120-Hz ripple; thus, the 120-Hz components of the ripple voltage were barely filtered. The ripple was drastically reduced by a redesign of the linear variable transformer. The new variable transformer has series-compensation coils to balance the output voltage at full load. The entire power supply system was tested at 800-kW load at NBS at the time of the klystron tests to determine the ripple level and other operating parameters. The new compensation windings in the second power supply at Los Alamos drastically reduced the ripple, to ~3% at full load. The ripple voltage at NBS is also about 3% from light loads to 800 kW. Further efforts to reduce this ripple are now under way.

The Crowbar

An ignitron crowbar unit originally was purchased as part of the dc power-supply package. This crowbar had a mechanical problem because the dual ignitron stack and its associated resistors were unpackaged initially. An interlocked metal enclosure was designed and built to test and safely operate the crowbar system. The original circuit required over 5 μs to trigger, and the metal enclosure containing the electronics and ignitron stack was too large to fit in the accelerator room at NBS. Therefore, a compact, pressurized spark-gap crowbar was designed and built[5] to save space and to shorten the firing delay in the original crowbar. The delay in the new spark-gap unit is about 2 μs, but the circuit is quite sensitive to the spark-gap trigger levels. If the trigger voltage is too low, the spark gap will fail to fire; whereas, a too-high trigger voltage either destroys the pulse transformer or rapidly erodes the trigger electrode on the vacuum spark gap. This problem can be minimized by careful adjustment of the trigger voltage, but the pressurized spark-gap crowbar will always need more maintenance than an ignitron crowbar. Another problem with the spark-gap crowbar is that the spark gap often stops conducting when the voltage reverses polarity in an oscillatory circuit. The power supply is 70 m from the crowbar, and the filter capacitor is rather small--only 1.3 μF. The crowbar damping resistors supplied with the crowbar were 2.5 Ω, nominally noninductively wound. The original crowbar circuit had enough inductance to be underdamped, and the spark-gap crowbar would extinguish on the polarity reversal. Even after increasing the new crowbar resistor to 4 Ω, the circuit still is slightly underdamped. The crowbar damping resistors are in series with the klystron; hence the power dissipated increases as the resistance value is increased. Since 1 kW is dissipated at full load in the 4Ω resistors, no further increases are practical because of the heat generation problems.

In the crowbar tests at Los Alamos, a 1-mm hole was made in a thin aluminum foil four times out of five. On the other trial, the crowbar would open on the polarity reversal, and a 5-mm hole would be made in the foil. This reliability was too poor for the spark-gap crowbar to be used with the klystron, and the ignitron crowbar was carefully re-examined. Most of the delay was in the trigger circuits. The fast-trigger circuits that were developed for the spark-gap unit were incorporated into the ignitron design. The ignitrons have "keep-alive" electrodes to sustain conduction in an underdamped circuit. By carefully repackaging and using new resistors, the ignitron crowbar could just fit within the small enclosure that was designed for the spark-gap crowbar. The redesigned ignitron crowbar has been tested at Los Alamos and the NBS and it is very reliable. The trigger delay is 2.5 μs, and the ignitrons conduct, even through a current reversal. The spark-gap crowbar remains with the second power supply, located in Los Alamos. The lead inductances have been reduced by using a coaxial connection between the power supply and the crowbar, and the circuit is now almost critically damped.

Conclusions

The low-level and high-power rf systems have been operated to full power at Los Alamos and shipped to NBS. The low-level system has been operated with beam at NBS and the high-power system has been operated there to 800 kW of dc input power and 240 kW of output power. This is over twice the rf power required to perform the injector tests that are scheduled for this July. Several problems remain in the high-power system, but these are the normal initial commissioning problems associated with any large system.

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