PROGRESS REPORT ON THE NBS/LOS ALAMOS RTM*

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Abstract

The NBS-Los Alamos 200 MeV Racetrack Microtron (RTM) is being built under a program aimed at developing the technology needed for high-current intermediate-energy CW electron accelerators. In this report we give an overview of the present status of the project. Recent progress includes: (1) completion of testing of the 100 keV chopper-buncher system demonstrating a normalized emittance well under the design goal of 2.6 π mm mrad at currents exceeding the design goal of 600 μA; (2) operation of the rf structures comprising the 5 MeV injector linac at power levels up to 50 kW/m, resulting in an accelerating gradient at $\beta=1$ of 2 MV/m (compared to a design goal of 1.5 MV/m). The measured shunt impedance is 82.5 MΩ/m; (3) construction and installation of the 30 ton end magnets of the RTM. Field mapping of one magnet has been completed and its uniformity exceeds the design goal of ± 2 parts in 10^4; (4) performance tests (with beam) of prototype rf beam monitors which measure current, relative phase, and beam position in both transverse planes. (5) Installation and initial operation of the primary control system.

Introduction

A continuous wave (CW) racetrack microtron (RTM) is being built at the National Bureau of Standards as part of a joint research project by NBS and the Los Alamos National Laboratory. The original goals of the project, begun in 1979, were to determine the feasibility of building a 1-2 GeV, high-current, CW electron accelerator using beam recirculation and room-temperature rf structures, and to develop the technology necessary to build such accelerators.[1]

The accelerator under construction at NBS has a design energy of 185 MeV. Although its construction will not be completed until late in 1986, several major subsystems have been completed and tested with excellent results.

In this paper we will review the design of the RTM, and describe progress in its construction and testing since the last Particle Accelerator Conference.

RTM Design

An overall view of the RTM is shown in figure 1. Major subsystems shown in the figure include: the 100 keV gun and chopper-buncher system; the 5 MeV injector linac; the microtron proper, including the 12 MeV accelerator and the two large end magnets; and the rf power source and power distribution system. Design parameters of the RTM are summarized in Table I.

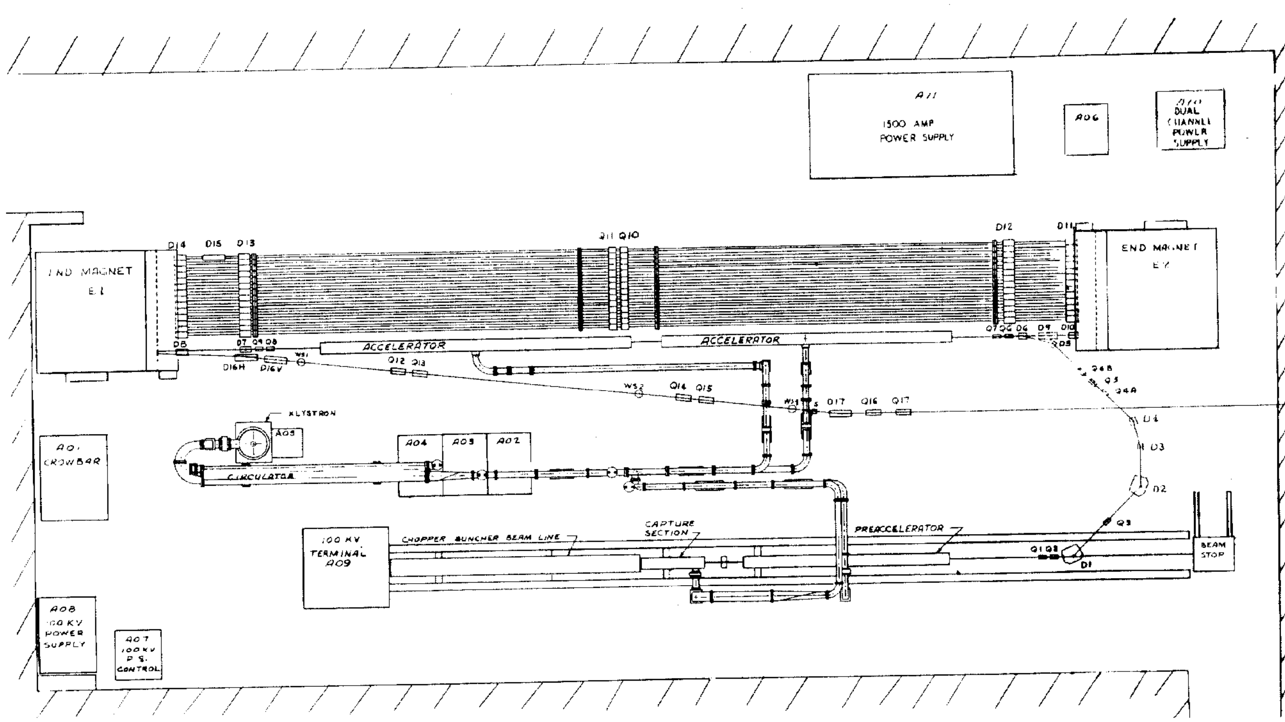

Figure 1

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TABLE 1. NBS-LOS ALAMOS CW RTM DESIGN PARAMETERS

Injection energy	5 MeV
Energy gain per pass, ΔV	12 MeV
Number of passes	15
Maximum energy	185 MeV
Maximum current	550 μA
Macroscopic duty factor	100%
RF frequency	2380 MHz
RF wavelength, λ	12.596 cm
Increase in orbit circumference per pass ($\nu\lambda$)	2λ
End magnet field, B	1.0 Tesla
Gradient in accelerating section	1.5 MV/m
Transverse tunes, ν_x - 1 and ν_y	Variable, 0 to 0.25
Longitudinal tune, ν_z	0.25
Normalized transverse emittance, ε_n	<10π mm-mrad
Longitudinal emittance, ε_z	<30π keV-degrees
Power source	One 500 kW klystron

The RTM is equipped with quadrupole doublets on every return path, strong enough to give a betatron phase advance of up to 0.25 per circulation. This is much stronger focusing than in the "conventional" race-track microtron which employs focussing only on the accelerator axis. The stronger focussing is provided to raise the threshhold for beam breakup (BBU).[2]

The resonance condition for the RTM is[3]

$$\frac{2\pi}{c} \Delta V \cos \phi_r = \nu\lambda B, \qquad (1)$$

where ϕ_r is the synchronous phase difference between the stable particle and the rf field in the accelerator. The other symbols are defined in Table I. Our choice of λ was dictated largely by the commercial availability of a suitable klystron. A desire to develop prototypical equipment for a 1 GeV RTM or a 2 GeV double-sided microtron[4] dictated a large value of ΔV. This, together with the need for return-path quadrupoles led to the choice ν = 2. The tolerance in field uniformity of the end magnets, which is inversely proportional to ν, becomes ± 2 parts in 10^4.

Gun and Chopper-Buncher System

This system consists of a 100 keV 5 mA electron gun, a phase-space matching and emittance limiting section consisting of two solenoid lenses and two apertures, a two-cavity rf chopper to chop the beam into micropulses of 60° rf phase length in each rf cycle, and a single-cavity buncher to compress the micropulses to 10° phase length. A detailed description of the system is given in reference 5. Since that report, the chopper-buncher rf structures and drives have been completed,[6] and the entire system has been tested with beam.[7] CW beam currents up to 0.74 mA have been chopped and bunched, with transverse envelope emittance below the design value of 4π mm-mrad (at 100 keV).

Injector Linac

The 5 MeV injector linac consists of two rf structures of the side-coupled type. The first is a 1 m long tapered-β capture section to accelerate the beam from 100 keV to approximately 1 MeV. This is followed by a 2.7 m long "preaccelerator" section[8] which has only a very slight β-taper (.98 to 1.0). The preaccelerator section has an effective shunt impedance of 82.5 MΩ/m. It attains the required accelerating gradient of 1.5 MV/m with a power dissipation of 27 kW/m. This section has been tested up to a power level of 50 kW/m (2 MV/m gradient). The capture section attains its design field strength and distribution at a power level of 25 kW. It has been operated to 30 kW.

RF Power System

The main rf power system consists of a 65 kV 16.5 A DC power supply, a 500 kW klystron, a power circulator to protect the klystron from sudden changes in load, and a distribution network of variable power splitters and phase shifters to drive the four rf structures (capture section, preaccelerator, and two 4m sections in the microtron) with the correct phases and amplitudes. The distribution network can be seen in figure 1. An overall description of the system is given elsewhere.[9,10] The system has been tested at Los Alamos with the preaccelerator and capture section as loads,[10] and is now being installed at the NBS site.

End Magnets

The end magnets must have an extremely uniform field over a region of approximately 1.2 x 0.6 m^2, and a non-focussing fringe field profile.[11] Uniformity of the end magnet field determines the phase error with which the beam returns to the accelerating section. For an error limit of ±1°, the field uniformity, $\langle \Delta B/B \rangle$, must be $\pm 2 \times 10^{-4}$ or better, averaged over any pass (180° bend) in either end magnet over the operating range of 0.8 to 1.2 Tesla. A novel design consisting of a half-picture frame magnet with a modified Purcell filter and an active field clamp has been developed.[12] The magnets have been installed and one of them has been mapped with a precision field mapper[13] which employs NMR probes to scan the uniform field region and a Hall-effect probe to scan the fringe field. The results are being presented at this conference,[14] and are briefly summarized here. The range of $\langle \Delta B/B \rangle$, as defined above, for all passes through the uniform field region is 7×10^{-5} at 1.0 Tesla, or about six times better than required. At 0.8 Tesla, the field is somewhat more uniform than at 1.0 Tesla, and at 1.2 Tesla, the uniformity still exceeds specifications. This excellent uniformity was achieved without resort to the pole-face correcting windings contemplated in reference 14. The measured fringe field shape is essentially indistinguishable from the design calculations.[12]

Control System

We employ a control system with a three-tiered heirarchy of microprocessor-based control elements, consisting of a primary station and multiple secondary and tertiary stations.[15] A PDP-11/44 minicomputer interfaced with the primary station provides offline and realtime control parameter calculations, generates stored or calculated control inputs, and provides other higher level system support functions. At present, the control system is about 80% complete in the basic configuration needed to test and operate the entire RTM system. Interconnection wiring, debugging, and writing of applications software are in progress.

Beam Line Instrumentation

Prototypes of several types of beam monitors have been tested in the 100 keV beam line, and are being produced in quantity for use throughout the RTM. We use chromium-doped aluminum-oxide-on-aluminum viewscreens viewed by TV cameras for beam visualization. These proved especially valuable for setup of the chopper system,[7] but cannot be used with high-current cw beams. We have developed flying-wire beam profile scanners[16] which can be used in either CW or pulsed beams. The 30 μm carbon fiber sensing element can survive indefinitely in an 0.6 mA relativistic electron beam with a diameter of less than 1 mm. The soatial resolution of these scanners has been demonstrated to be <50 μm. For non-intercepting measurement of beam position (in both transverse planes), phase, and current we have developed a monitor system employing two rf cavities tuned to the fundamental beam frequency (2380 Mhz). The first cavity has a square cross section that supports the TM210 and TM120 modes and is sensitive to the product of beam position and current. The second cavity is cylindrical, supports the TM010 mode, and is used to measure beam current and phase. A prototype rf monitor package has been tested with both pulsed and cw 100 keV beams. The position monitor was found to have a position resolution of <20 μm for a 100 μA beam, and to be linear for displacements up to 3 mm. The current monitor has a resolution of 8 μA, and has a linear response for both pulsed and CW beams. The phase detector has a resolution of <1° of rf phase. The current and phase signals are independent of beam position, and all signals are independent of beam size. Details of the rf monitor system are given in reference 17.

Completion Schedule

The major activity in the accelerator vault at present is installation and testing of the rf power distribution system. Upon completion of this task, the 5 MeV injector linac will be tested with beam. This is scheduled to begin in August 1985. Meanwhile, construction of the 12 MeV accelerator for the microtron is nearing completion at Los Alamos, with delivery scheduled for August 1985. Full power tests of the 8 m accelerator will be performed soon after installation. Following 5 MeV beam tests, installation of the remaining RTM components will take about one year. Thus we expect to complete the construction of the machine late in 1986. This will be followed by an extended period of performance tests including emittance and energy spread measurements as functions of beam current, energy, and accelerator tune. Determination of the BBU threshhold as a function of tune will be included in the performance tests. This schedule should make the RTM available for users on a part-time basis early in 1987. Contemplated uses include: nuclear physics coincidence experiments, high-energy electron and photon dosimetry, analytical chemistry, and free electron laser (FEL) development.[18]

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