LA-UR-80-1856

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SUBMITTED TO:

XIth International Conference on High Energy Accelerators,
CERN, Geneva, July 7-11, 1980.

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ABSTRACT

The NBS-LASL racetrack microtron (RTM) is a joint project of the National Bureau of Standards (NBS) and the Los Alamos Scientific Laboratory (LASL). This is a new accelerator research project whose goal is to determine the feasibility of building a high-energy, high-current, cw electron accelerator using beam recirculation and room-temperature rf acceleration structures. The NBS-LASL RTM is being designed and built to develop the required technology for a large national 1 to 2 GeV cw accelerator for nuclear physics research and to prove experimentally that high currents can be accelerated successfully in an RTM. Some of the parameters of the NBS-LASL RTM are 185 MeV final energy, 550 μA maximum current, 15 passes, 12 MeV one-pass energy gain, and 2380 MHz frequency. One 450 kW cw klystron will supply rf power to both the 5 MeV injector and the 12 MeV linac in the RTM.

1. INTRODUCTION

In principle, the electromagnetic interaction is the ideal experimental tool for studying nuclear structure because it is weak and well understood. In fact, the study of electronuclear and photonuclear reactions has contributed greatly to our understanding of nuclei. Nevertheless, electron accelerators are relatively little used compared to proton and heavy ion machines, largely because it is difficult to perform experiments with electrons or photons. These difficulties arise from the small size of electromagnetic cross sections, the unavailability of monoenergetic photon sources, and the poor duty cycle of most existing electron accelerators. Recent technological advances have raised the exciting possibility that new types of electron accelerators can be built, at acceptable cost, that will provide high-current, continuous-duty (that is, cw) electron beams, thus alleviating the experimental difficulties mentioned above.

The NBS-LASL racetrack microtron illustrated in Fig. 1 is part of an accelerator research project whose goal is to determine the feasibility of building a 1 to 2 GeV, 100% duty cycle electron accelerator that can generate at least 100 μA[1,2]. It is quite clear that the least expensive accelerator design that can achieve these parameters is the racetrack microtron, or similar device, in which the beam is recirculated through the same accelerating structure many times.

We designed the RTM to be as applicable as possible to the 1 to 2 GeV machine. The specific choice of the 2380 MHz operating rf frequency was dictated by the desire to provide multiple, simultaneous, high-current beams to several users by subharmonic rf splitting and by the commercial availability of a high-power (450 kW) cw klystron. The 12 MeV one-pass energy gain, which requires a magnetic field of about 1 T the end

*) Work supported in part by the Division of Nuclear Physics, Department of Energy.

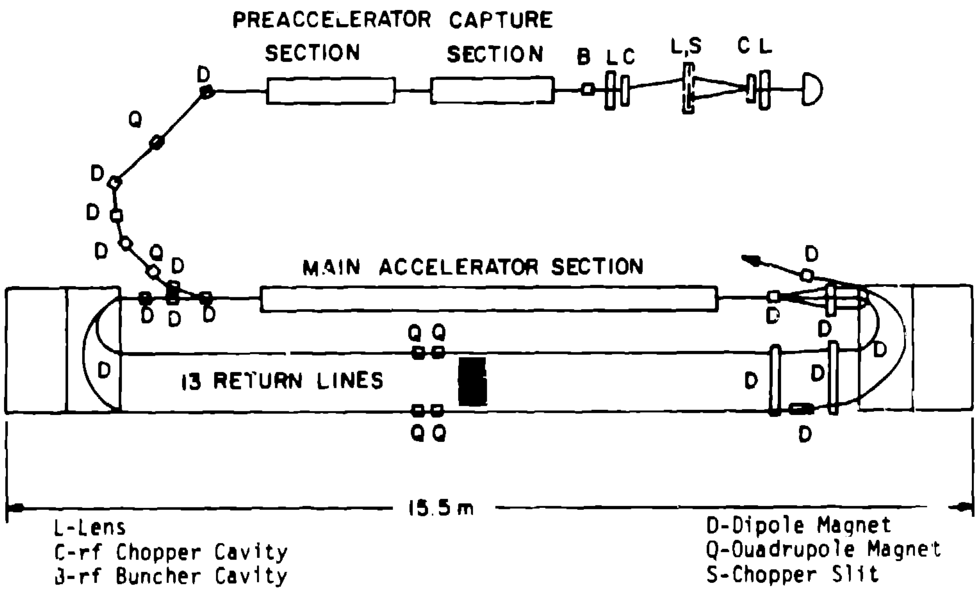

Fig. 1. NBS-LASL Racetrack Microtron (15 passes, 12 MeV/pass, 185 MeV).

magnets, is essentially one-fourth of the optimum energy gain per pass of a high-energy double-sided microtron and thus serves as a prototype accelerating module. The final 185 MeV beam energy is estimated to be near the injection energy required by a high-energy double-sided microtron; thus the RTM serves as a prototype of the injector needed by the larger machine.

We have chosen room-temperature rf accelerating structure over superconducting structure for two reasons. First, a large amount of rf power is required to provide the beam power in a high-current accelerator; thus room-temperature accelerating structures can have a high (rf to beam) power conversion efficiency. Second, the current in a microtron is expected to be limited by beam blowup caused by excitation of transverse rf modes by the beam. We expect the limiting current to be inversely proportional to the quality factor, Q, of the responsible rf modes and inversely proportional to the number of passes[3,4]. Because the Q-values are substantially smaller in a room-temperature rf accelerating structure than in a superconducting one, a much higher current limit is obtainable with a room temperature structure.

2. INJECTION SYSTEM

The injection system must provide a cw electron beam to the microtron with the following specifications:

1. The injection energy must be ~ 5 MeV.
2. The injected current must be continuously adjustable from zero to 0.6 mA.
3. A pulsed beam mode must be available for tuneup and diagnostics with a 40 ns FWHM pulse length, which is shorter than the microtron's circulation time.
4. The normalized transverse emittance must be < 5π mm·mrad.
5. The longitudinal emittance must be < 20π keV·degrees.

The injection system will consist of a 100 kV electron gun, an rf chopper-buncher system, a 2 MeV rf capture section, an rf preaccelerator section for an additional 3 MeV energy gain, and a beam-transport system to carry the 5 MeV beam to the microtron. The electron gun will have a modulating anode for current control. The high voltage will be applied between the grounded final anode and the cathode, so that the control voltage applied to the modulating anode does not affect the beam energy. A pulser located in the high voltage terminal will provide the pulsing capabilities specified above.

The rf chopper-buncher system consists of a pair of rf chopper cavities, a phase-selecting aperture, magnetic focusing lenses, and an rf buncher cavity. The chopped, bunched beam proceeds to the rf capture section where acceleration begins.

3. MICROTRON DESIGN

In an RTM[5], the beam is returned to the accelerating section by uniform field end magnets, as shown in Fig. 1. On successive passes, the beam must pass through the accelerating section at the same synchonous phase, ϕ_r, of the rf field. This resonance condition can be expressed by the relation[6]

$$(2\pi/c)\cdot\Delta V\cdot\cos\,\phi_r = \nu\lambda B \quad . \tag{1}$$

where $\Delta V\cdot\cos\,\phi_r$ is the resonance energy gain per pass, λ is the rf free-space wavelength (12.5963 cm), B is the end-magnet field strength, and ν the harmonic number. We have chosen to use $\nu = 2$, which makes the spacing between successive return paths $d = \nu\lambda/\pi = 8.019$ cm (when $\beta = 1$, the electron velocity in units of c). This spacing is sufficient to allow installation of independent steering and focusing elements on each return path. The major disadvantage of $\nu = 2$ compared to $\nu = 1$ is the reduced longitudinal phase acceptance of the RTM. Because of this, we will strive to keep the longitudinal emittance of the injected beam well within the design specification of 20π keV·degrees. We will use a reverse return after the first pass through the main accelerating section. The second and subsequent passes will be in the opposite direction from the first pass. Sufficient focusing for the first two passes will be provided on the accelerator axis, whereas later passes will have focusing on the return paths. Extraction can be accomplished after any number of passes by a movable kicker magnet on the return paths. The kicker magnet deflects the beam onto a common extraction path from any return line.

The transport system needed to transfer the beam from the injector to the microtron must be a very high-quality achromatic system. The system chosen consists of two 90° deflection achromatic subsystems in series so that the full 180° system is also achromatic. The first 90° subsystem has a quadrupole singlet at the center and two dipole magnets, each providing a 45° deflection of the beam. The second subsystem is similar to the first except that each 45° bend is accomplished by a pair of magnets, with one providing a 15° deflection and the other providing a 30° deflection. This modification is used because the final magnet that provides a 15° deflection is also one of the three injection chicane magnets.

The diagnostic information needed to adjust the transport system will be obtained from instrumentation packages located on the axes of the injector and microtron linacs. These packages will contain phosphor view screens, wire scanners, and rf cavities for measuring x and y transverse position, rf phase, and beam current. Phosphor view screens and wire scanners will be placed on the return lines near each end of the microtron. The rf position, phase, and beam-current sensors placed on the axis of the microtron linac will use the pulsed beam for obtaining position, phase, and beam-current information for each pass. The beam pulse is shorter than the circumference of one pass through the microtron, thus the beam pulse produces a train of pulses in the rf sensors, each pulse corresponding to one pass through the microtron.

4. DISK-AND-WASHER ACCELERATING STRUCTURE

The RTM contains three rf accelerating sections: the capture section and preaccelerator sections of the injector linac, and the main accelerating section of the microtron. The rf accelerator structure will be the disk-and-washer (DAW) linac structure with T-shaped washer supports that is being developed at the Los Alamos Scientific Laboratory for both electron and proton accelerator application[7]. The DAW is a standing-wave structure that provides efficient acceleration of particles with $\beta > 0.5$. The field distribution in the structure is extremely stable as a result of the large cell-to-cell coupling and the characteristic of the $\pi/2$ operating mode. Figure 2 shows the DAW structure with the washers supported in pairs from four T-shaped supports. The radial portion of these supports lies along an equipotential of the accelerating mode, and the longitudinal portion of these supports lies in a region of low electric field. Consequently, this type of support minimizes the perturbation of the accelerating mode. However, these supports significantly perturb the coupling mode. Left uncompensated, these perturbations would open a stop-band in the mode spectrum and create a bilevel distribution in the excitation of the accelerating cells. Fortunately, by experimenting with the geometry of

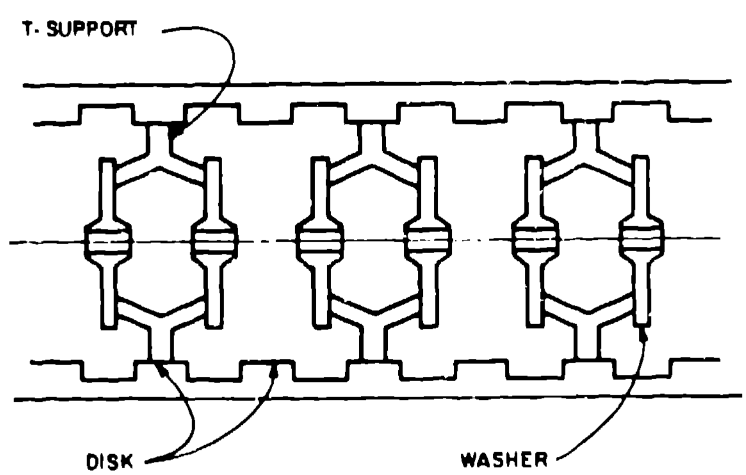

Fig. 2. Disk and Washer Linac Structure.

a low-power test section, a technique has been developed to counteract these perturbations. The geometry of the DAW (without washer supports) was optimized with the aid of the computer program SUPERFISH. (This program can calculate the resonant electromagnetic modes in an rf cavity with cylindrical symmetry.) The perturbations caused by the supports are counteracted by a cut-and-fit procedure in which the disks, on which the T-shaped supports are mounted, are made thinner, and the radius of the outer wall of the cavities is made larger.

In addition to supporting the washers, the supports provide channels for carrying coolant to and from the washers. The practical limit for cooling the 2380 MHz DAW structure is ~ 25 kW/m. An effective shunt impedance of ~ 100 MΩ/m appears to be attainable in the $\beta = 1$ structure and will result in an accelerating gradient > 1.5 MV/m. Thus, the main accelerator section will be ~ 8 m long to provide the 12 MeV energy gain required by the design parameters. The injector linac will consist of ~ 4 m of DAW structure. The first 2 m section is a capture section that will increase the beam energy from 100 keV to 2.0 MeV. In the capture section, the lengths of the rf cavities increase smoothly to match the increasing electron velocity (from $\beta = 0.55$ to $\beta = 0.98$). The second 2 m section is the preaccelerator section that accelerates the beam to the microtron injection energy of ~ 5 MeV. The construction of the 2 m preaccelerator section will be undertaken as soon as the details of the washer supports and the compensation for the perturbations they produce is finalized. A low-power test section is presently being studied. The tests of the 2 m preaccelerator section will determine the cooling capacity and multipactoring properties of the DAW structure.

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