DESIGN OF A 600 MeV SUPERCONDUCTING MICROTRON

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Introduction

The 600 MeV racetrack microtron proposed for the University of Illinois is an instrument which can supply an effectively continuous electron current of a few microamperes with an exceptionally low energy spread. It seems to be particularly suitable for use in nuclear research since it is modest in size and economical to operate and to maintain.

A racetrack design emphasizing the use of a room temperature linac has been discussed by Wiik and Wilson[1]. A report on the Illinois design emphasizing its beam transport aspects was reported earlier this year[2]. The superconducting accelerator section linac is based on the developments at Stanford University which have been extensively described[3, 4, 5]

General Arrangement

The proposed 600 MeV microtron consists of a 30 MeV superconducting linac, operating C. W. at 1.3 GHz, placed between 13.67 kilogauss bending magnets 640 cm apart as shown schematically in Figure 1. There are 19 parallel tubes, separated by 14.7 cm, each with two quadrupole pairs to guide the electrons back through the accelerating section until they finally emerge with the desired final energy.

Electrons start from the D. C. electron gun and gain a kinetic energy of 250 keV. These enter a TM210 mode microwave chopper which selects only those electrons within a 6° phase interval to be inflected by small magnets into the superconducting linac and subsequent microtron transport system.

Calculations

Detailed evaluation of the electron trajectories for a number of initial conditions have shown that the requirements for phase and space stability are easily satisfied[2]. The deviations from the nominal trajectory caused by a change of 1 percent in the linac voltage or of 0.3 percent in the guide field are shown in Figure 2 where it can be seen that there are no excursions away from the nominal orbit by more than 0. 5 cm. Quantitative specifications of the outgoing trajectories under these and other conditions are summarized in Table 1. The output energy can be seen to depend primarily on the magnetic field and to follow the variation in magnetic field to 0.002 percent.

Procuremeut of Components

Our microtron proposal specifies the construction of the superconducting linac in two sections, each housed in a separate cryostat. We have started the construction of one of these sections which consists of a niobium accelerator structure, 2.4 meters long, housed in a stainless steel cryostat. It is being installed next to the 20 MeV betatron which it will replace temporarily as a source of electrons for the coincidence photon monochromator arrangement. If it operates successfully a second similar unit will be made to complete the two section 4.8 meter linac proposed for the microtron. Most of the necessary auxiliary items required to inject electrons into this linac and to opera'e it are complete or are under construction.

Electron gun

The electron gun was delivered in May 1969 and is now operating. It is a modification of the 300 kV ion and electron accelerator system made by the Texas Nuclear Corporation primarily as a (D, T) neutron source. It has a completely enclosed high voltage electrode and can supply 5 milliamperes of D. C. current at any voltage below 300 kV with a precision of 0.1 percent. This current and voltage are comfortably above the 0.6 ma and 250 keV planned for the microtron.

Chopper

The electron beam chopper system consists of two cavities each operating in a TM210 mode at 1.3 GHz. These cavities were made in our own shops from a Stanford design. These cavities move the electron beam in an elliptical path so that the beam can pass through a slit system during one 6° phase interval in each microwave period. Two solenoidal lenses have been constructed to focus the beam in the chopper cavities and through the linac.

Inflector

The inflector system will consist of two small magnets D and C which make up an achromatic beam translation system. The magnets A and B on the linac axis restore the small deflection and displacements suffered by the beam in recirculating through magnet C. These are not required for the linac tests and are not yet completely designed.

Cryostat

The cryostat for the 2.4 meter niobium section will be 3 meters long and can hold 500 liters of liquid helium at 1.8°k. After considering a number of proposals for the construction of the cryostat the contract was awarded to Gardner Cryogenics. The cryostat will be made of stainless steel. The welded parts closest to the accelerating cavities will be annealed before assembly to reduce undesirable magnetic effects. In addition to the ports required for the electron beam and for microwave power, there will be an 8" diameter central opening to the inside of the 500 liter dewar as shown in Figure 3. This 8" neck will be used as a channel to the vacuum pump and as space for a low pressure 1. 8°k heat exchanger.

Refrigeration

Most of our work at low temperatures have been carried out using helium supplied as liquid but it is clear that this will not be economical or convenient for operating the 2.4 meter linac. In order to have a source of continuous refrigeration at 1.8°K, we have modified an old A. D. L. helium liquifier by adding a helium gas recovery system and a 1500 CFM vacuum blower. We have also ordered a low pressure heat exchanger to make use of the cooling available from the escaping 1.8°K helium vapor. This should increase the refrigeration available at 1.8°K from 5 to 25 watts. The heat exchanger will be mounted into the 8" neck of the 3 meter cryostat in order to deliver the maximum cooling to the linac structure. It should be available by January 1970 for the testing for the initial operation of the 2.4 meter niobium section. We hope it will also allow us to operate the section for nuclear physics experiments city for several hours a day, but we do not expect it to have the capa- or the reliability we need for the microtron.

Our proposal asks for a new unit with a cooling capacity of 100 watts at 1.8°K. This could take care of the wall losses in the proposed 4.8 meter of the biperiodic structure, operating as a 30 MeV accelera- and tor, if the Q of the structure was 1.5×10^9 or better.

Linac structure

Since our linac has a modest length we can afford to be conservative and have chosen to build the $\pi/2$ mode biperiodic structure developed at Stanford University. This structure is tolerant of dimensional errors and of nonuniform loading in individual cavities. Its specific shunt impedance r/Q was reported as 920 ohms per meter at 0.95 GHz which scales to 1260 at 1.3 GHz. The power V^2/rL absorbed in 2.4 meters of structure, operating with V at a 15 MeV level and with a Q of 1.5×10^9, is 50 watts. If this Q is also applicable to the beam blowup modes, the maximum current is given by $\frac{V}{3}\lambda^2_\perp/(40\ L^2Q_\perp)$ where $\lambda_\perp$ for our structure is about 16 cm, and the limiting current is about 0.50 microampere. This is considered a useful current for some of the immediate experiments and no special features will be introduced into the structure at this time to reach higher currents. The cavities for the initial $3\lambda/2$ and $5\lambda/2$ sections are to be machined from solid niobium disks which will be electron beam welded into a single cylinder. These will then be outgassed and annealed in the large Stanford high vacuum oven at about 1900°C.

Microwave electronics and power sources

The basic frequency source for both the test program and the operation of the linac is a frequency synthesizer which generates signals up to a frequency of 0.5 GHz. This synthesizer is followed by a frequency tripler and a traveling wave amplifier capable of supplying 20 watts of microwave power in the frequency range from 1 to 2 GHz. For 2.3 GHz or 2.6 GHz tests, this traveling wave amplifier is followed by a varacter doubler to supply up to 3 watts of power.

For higher power applications at 1.3 GHz we have a 150 watt voltage tunable magnetron which can be phaze locked to a drive line and is useful for power tests of cavities, power probes, and auxiliary devices. The main power sources, however, will be the Eimac Varian X3002A one kilowatt klystrons which have a gain of 23 db and can be driven directly from the traveling wave amplifier. For the initial tests one of these klystrons will supply power to the chopper and the other to the main section of the linac. The amplitudes and phases of the electromagnetic fields in the chopper cavities and the different sections of the linac will be monitored and controlled by feedback stabilization systems similar to those developed by Suelzle[5]. The microwave components are being designed and constructed using integrated microstrip techniques. These techniques should greatly increase the system reliability while reducing the size and cost of the system from that using separate components. These are being assembled to fit the standard transistor power supplies and packages developed at the University of Ilinois for use in high energy physics.

Unresolved Problems

The major factor which will determine the usefulness of the linac is the performance of the superconducting accelerating section. Although the extrapolations from the work with small niobium cavities do not indicate any basic limitations, there may be many practical problems in producing and maintaining the quality of the surfaces in large structures. If the surface quality is good, beam blowup, due to the excitation of deflection modes, is expected to limit the beam current. We are, however, building the regular $\pi/2$ mode biperiodic structure without any modification at the present time and hope to study methods of controlling such oscillations usiug the sensing and power probes built into the structure for other purposes.

The microtron calculations indicate that there are no basic difficulties in the microtron transport system but there are a number of practical aspects of the design which deserve further consideration. One of these is the fringe field terminations for the 180° magnets suggested by Babic and Sedlacek[6] which could reduce the alignment tolerance and the stability required from the quadrupole focussing system.

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Table 1

Properties of the electron beam from the microton in the 20th return path for different injection phases, accelerating voltages and magnetic fields. The nominal specifications of the beam injected into the linac for the trajectories considered here are: $V_i=0.250$ MeV, $\varphi_i=-70°$, $X_i=Y_i=+2$mm, $(dX/dZ)_i=(dY/dZ)_i=0$. Those from the linac after the first traversal are: V=29.33 MeV. X=Y=0.4 mm; dX/dZ=dY/dZ= = −0.04 mr. The resonant energy gain for these conditions are 29.17 meV at a resonant final phase of 9° with a magnetic field of B=13,237 gauss.

Operating Conditions	Outgoing Beam					
	X mm	dX/dZ 10^{-6} rad.	Y mm	dY/dZ 10^{-6} rad	E_{out} MeV	ΔE_{out} Percent
Nominal Phase	−0.77	−4.5	−0.28	−17.0	583.29	0.000%
$\varphi-\varphi_1=+3°$	−0.94	+6.7	−0.36	−10.0	583.35	−0.010%
$\varphi-\varphi_1=-3°$	−0.66	+2.4	−0.23	−21.0	583.25	+0.007%
$\Delta V/V=+1.0\%$	−1.10	+0.03	−0.13	−10.0	583.42	+0.022%
$\Delta B/B=+0.3\%$	−0.68	+2.0	−0.01	−10.0	585.03	+0.298%

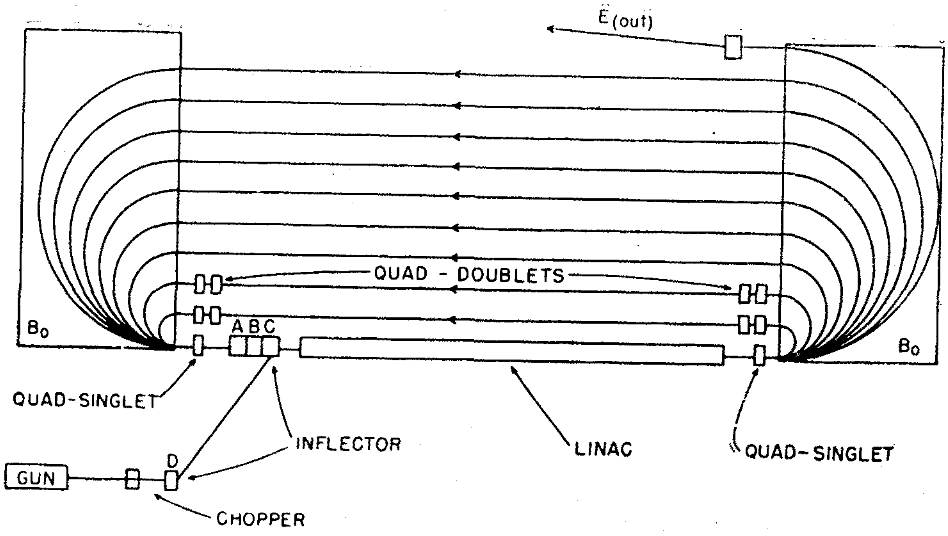

Fig. 1. Schematic microtron arrangement.

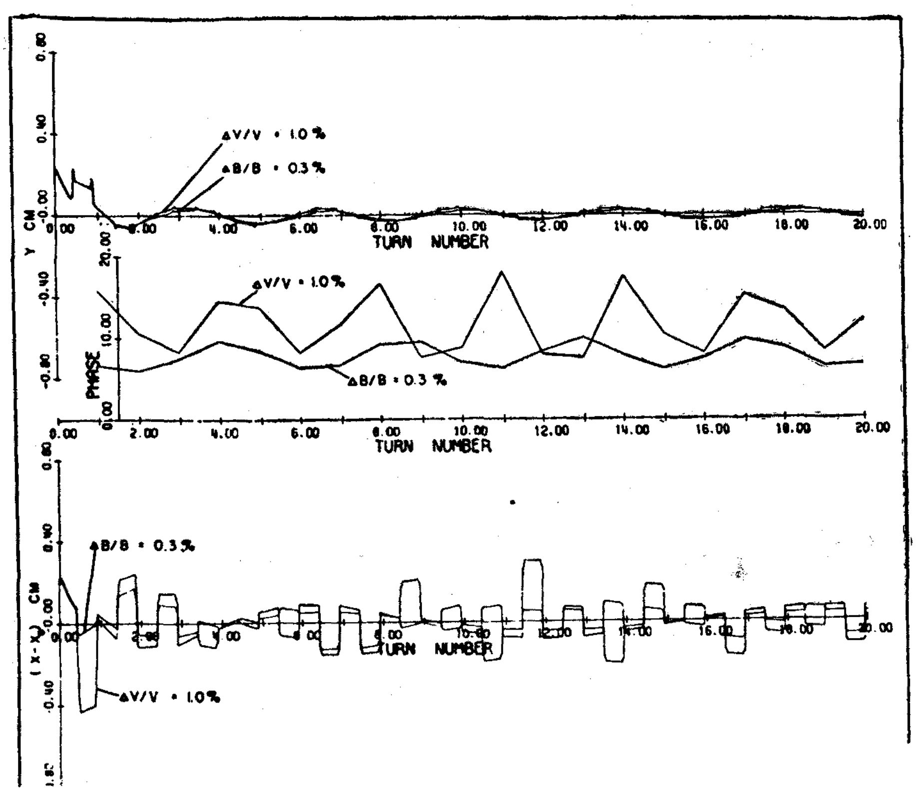

Fig. 2. Electron trajectories for a 1% increase in the linac energy gain with nominal B and a 0.35 increase in B for the nominal energy gain in the linac.

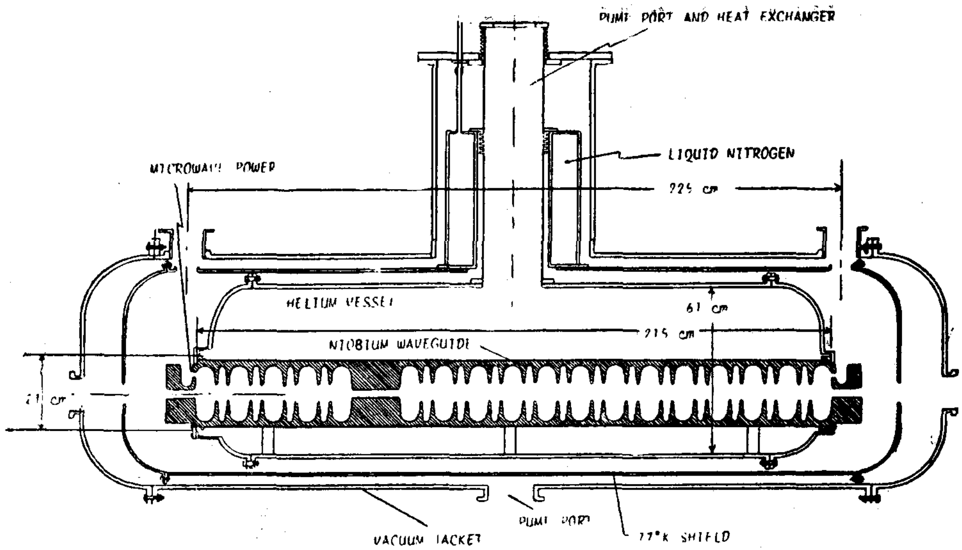

Fig. 3. General plan of the cryostat.