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MICROTRON USING A SUPERCONDUCTING ELECTRON LINAC

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Summary

The superconducting linac of the 6 pass microtron (MUSL-1) described previously has been operated at 4.2 K for about 3 years with an energy gain of 2 MeV/meter. The duty factor has been limited to about 50% by thermal effects. A new helium liquefier supplies more than the 13 liters per hour required to operate the linac continuously at its maximum duty factor. The system can supply 5 μa of electrons with energies up to 19 MeV and has been operated on a 24 hour per day schedule for nuclear physics experiments.

A larger system (MUSL-2) utilizing a surplus 3 MeV Van de Graaff as an injector and a 6 meter superconducting accelerator section made for us at Stanford University is being assembled in another area. Although the installation is not yet complete microwave tests indicate that the section can be operated continuously with an energy gain of 13 MeV with an input power of about 10 watts. For the initial operation of MUSL-2 the 6 pass hardware from MUSL-1 will be used to recirculate the electron beam through the new linac section to a final energy of 60 MeV.

Operating Experience With MUSL-1

A plan view of the linac cryostat and the associated recirculation system of MUSL-1 is shown to scale in Fig. 1. A photograph of the system is shown as Fig. 2. Electrons of 270 keV are chopped, bunched, and deflected onto the linac axis where they are accelerated to 0.7 MeV by the 3/2 λ section and to 3.5 MeV by the 13/2 λ section. Because the effective phase difference between the two sections is about 70 degrees for relativistic electrons, little energy is contributed to the recirculated beam by the 3/2 λ section and the energy gains on the subsequent passes is only 3.1 MeV. The electrons are returned to the linac by uniform field magnets whose pole pieces are 114 cm wide and 56 cm deep. The active magnetic clamps extend along the entire entrance edge of the turn-around magnets and provide a reverse field of about 10 percent of the main field to compensate for the defocusing of the fringe fields as well as some additional vertical focusing. There are a number of cylindrical lenses made up of uniform field triplets which are useful in adjusting the vertical focusing on the separate return paths. In Fig. 1 one can identify the bypass for the first return beam which provides a phase adjustment from 40 to 160 degrees. A bypass of only 4 degrees carries the second return beam around the other side of the cryostat. The special features of these components were described briefly in the previous report on recirculation[1]. All the magnets in the system are simple rectangles which have a focusing effect only in their vertical direction. The horizontal focusing takes place only on the common linac axis by means of the linac fields and by two quadrupole singlets which are on this axis.

The phases of the returning first, second, and third pass beams are adjusted by means of the bypass angle, the magnetic field in the end magnets, and the spacing between them. The phases of the fourth and fifth pass beams need only small corrections which are made with pole face currents that affect the magnetic fields in strips covering only the outer portions of their semicircular paths.

The beam, after 3, 4, 5, or 6 passes through the linac can be deflected by 17 degrees into a common channel that leads to the two 36.5 degree rectangular magnets which bend the beam into the experimental area. These exit magnets have no horizontal focusing and their spacing is adjusted to remove the focusing in the vertical direction. The exit magnets have a useful dispersion of 30 mm for a 1 percent momentum change at a point about 2 meters away. By observing the structure of the beam on a view screen at this point it is possible to readjust the phases of the return beams to reduce the energy spread in the beam to less than 0.1 percent. Optimization of the adjustments, however, is not straightforward since the phase adjustments for the first three returns are interrelated and can be optimized only by successive readjustments of a number of components. After the adjustments have been made properly the beam has often remained stable and reliable on an experimental target for many hours without operator intervention. Under these conditions the beam is confined within a radius of 6 mm in any of the 6 meter straight sections in the return paths and there is no loss of beam in the recirculation system.

Computer simulations of the electron trajectories, phases, and energy gains under various operating conditions were carried out in order to understand the system. The result of one of these simulations, for a linac energy gain 0.4 percent above its nominal value, was presented in a previous report[2].

The 3/2 λ and the 13/2 λ niobium sections have operated reliably without disassembling the cryostat and without any major difficulties for about three years. These sections which were processed only by chemical polishing had initial Q values above 10^8 but now have values of $4\ 10^7$ and $8\ 10^7$ respectively. These are operated at 4.2 K with energy gains of 2 MeV per meter and would require 100 watts of cooling at that temperature if operated continuously. Although our refrigerating system can supply the required refrigeration, the duty factor is limited to about 50 percent due to thermal effects in the 3/2 λ section. Usually the operation of the linac is started with liquid helium covering the niobium structure by more than 10 cm and its operation is continued at the same duty factor until there is essentially no liquid helium left in the cryostat. Apparently the liquid helium level has no effect on the operating characteristics of the superconducting sections.

The tuning of the 3/2 λ section to match the frequency of the main section has not been a problem. If the atmospheric pressure remains constant the section can be operated without adjusting the tuning for several days. There is, however, some phase jitter between the sections associated with mechanical vibrations. This introduces jitter in the energy gain through the two sections of the order of 5 keV.

For the past two years beams with energies up to 19 MeV have been delivered to two experimental areas. In one of these areas a GeLi detector was used to study resonance fluorescence from nuclei at energies below their neutron thresholds. The second experimental area contains the tagged photon facility usually referred to as the photon monochromator. The tagged photon beams were used to study elastic photon scattering, photoneutron cross sections, and photofission.

Plans

A higher energy system which uses a single 6 meter superconducting accelerator section and a surplus 3 MeV Van de Graaff as an injector is being assembled in the larger area previously occupied by 300 MeV betatron.

The superconducting linac was made for us at the High Energy Physics Laboratory of Stanford University using their designs. The niobium section was assembled and evacuated at Stanford University and was kept under vacuum during shipping and mounting into a standard HEPL cryostat at the University of Illinois. The structure was cooled down and covered with superfluid helium down to 2.0 K. Microwave measurements indicated that the structure could sustain an energy gradient of 2 MeV/meter without excessive field emission. At 2.1 K measurements indicated a total energy gain of 13 MeV with about 10 watts of C.W. microwave power absorbed in the structure. At this power level the x-ray intensity due to field emission in the structure was 10 milliroentgens per hour just outside the cryostat. The continuous level of energy gain decreased to about 12 MeV as the temperature was allowed to increase through the lambda point to 2.2 K at around 40 torr. When the pressure was allowed to return to one atmosphere at 4.2 K, the maximum continuous energy gain remained at 11 MeV when the section was covered with liquid helium and also when the liquid level was completely below the structure. The energy gain for continuous operation was limited to 10 MeV for gas cooling at 2 K.

The higher energy injection using a 3 MeV Van de Graaff was chosen in order to avoid the difficulties associated with operating another superconducting system in a separate cryostat. The 3 MeV electrons are within 1% of the velocity of light and can be injected through the 49 $\lambda/2$ structure with no more than a 90° phase lag even with a very low energy gradient in the structure. Because the Van de Graaff is not capable of accelerating currents larger than about 100 microamperes it would be difficult to operate directly on the 3 MeV beam and deliver a 10 microampere beam bunched within $\pm 1^{\circ}$ to the linac. One must, therefore, chop and bunch the beam in the high voltage terminal of the Van de Graaff so that only the chopped beam is accelerated to 3 MeV.

In order to simplify the electronics and the associated controls inside the terminal we plan to use a rather unconventional injector arrangement. The system uses an electron gun which supplies a narrow electron beam at 50 keV. This beam passes directly through a 1.3 GHz buncher cavity which modulates the energy of the beam by ± 2.2 keV. The modulated beam enters a uniform magnetic field where it is bent 180° to a slit which passes only the beam within ± 1.1 keV of the 50 keV. The selected beam is then bent through another 180° to the original direction. The selected beam contains a phase interval between -30° and $+30^{\circ}$ and the modulation is correct to get the beam to collapse to a minimum size inside the 3 MeV accelerating column. The second beam packet that crosses the slit as the energy decreases is debunched and expands to about $\pm 60^{\circ}$ before it reaches the accelerating column. With this arrangement the 3 MeV beam includes the desired 10 microamperes in tight bunches together with 10 microamperes which is debunched. The debunched beam is removed by a synchronized chopper external to the Van de Graaff while the bunched beam will be transmitted to the superconducting linac. The bunched beam passes through a passive 1.3 GHz cavity near the linac entrance which is used to monitor its amplitude and phase. The phase is compared to that of the microwave system reference and a D.C. error signal will be transmitted to the high voltage terminal via a light link to adjust the phase of the microwave oscillator.

Initially the recirculation of the beam through the new linac will be made using the 180° magnets and much of the associated hardware shown in Fig. 1. Because of the small size of the magnetic yokes in these magnets the maximum energy of the 6 pass beam will be limited to about 60 MeV. A proposal is being made to extend the system to 20 passes utilizing the maximum energy gain of the 6 meter linac.

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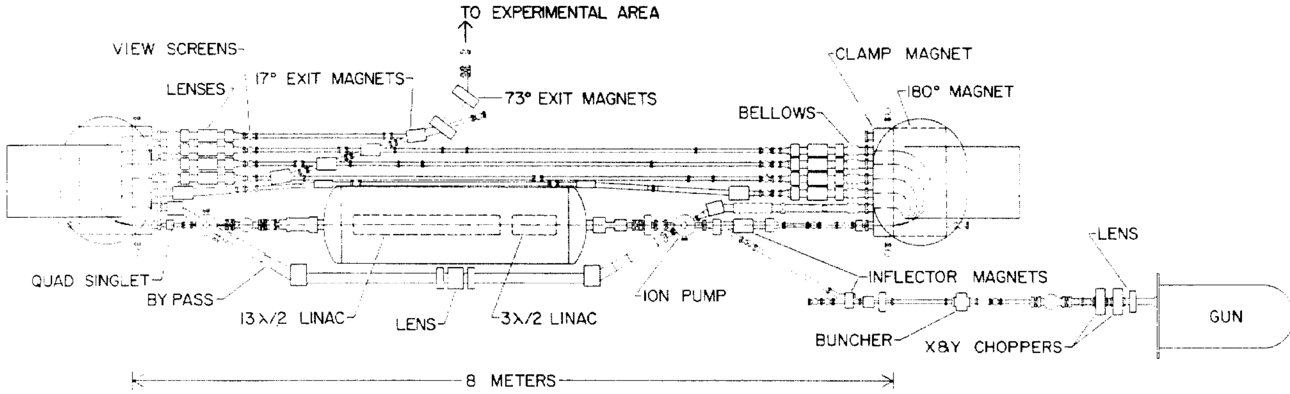

Fig. 1. Experimental arrangement of the six pass microtron (MUSL-1).

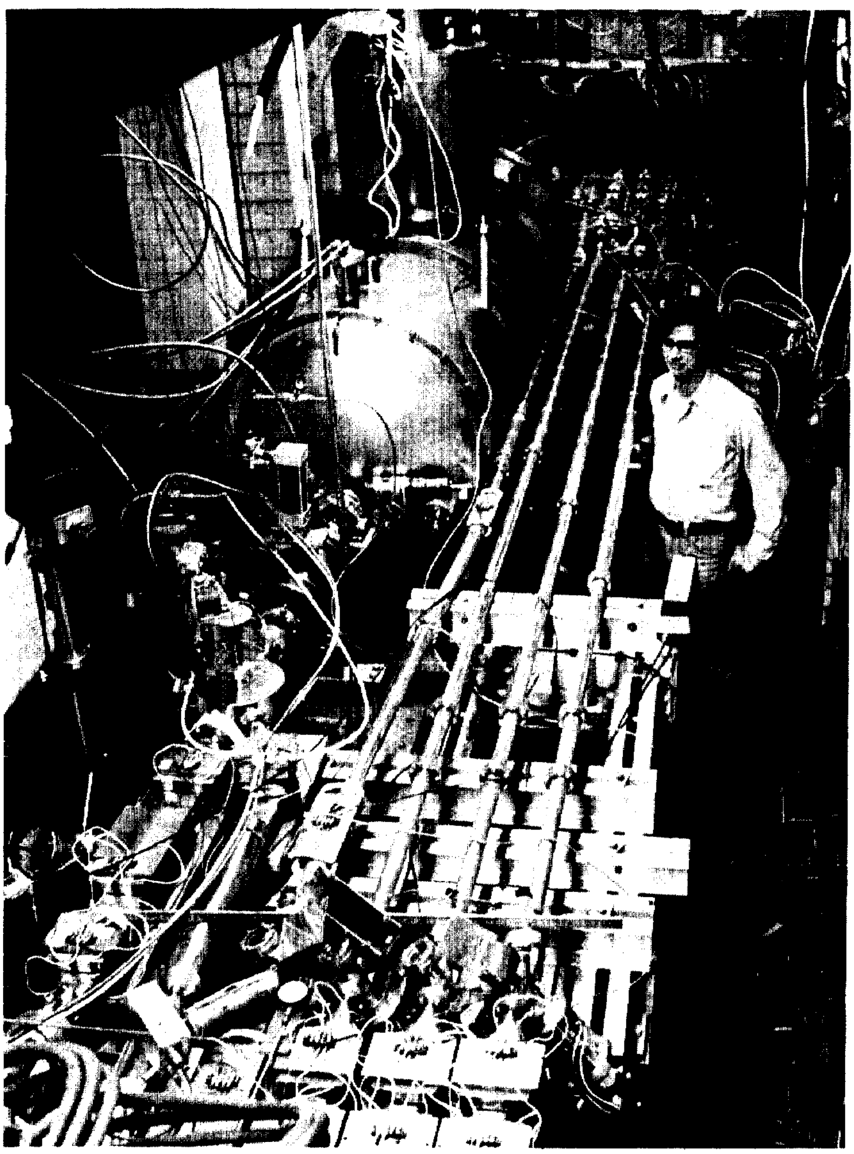

Fig. 2. Photograph of MUSL-1 showing the cryostat and the pipes returning the beams from the uniform field magnet in the top of the picture. The injected beam is deflected onto the linac axis at the lower left. Some of the bypass for the first return beam can be seen around the left side of the cryostat crossing the linac axis and going toward the 180° magnet just out of the lower part of the picture.