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STATUS OF MUSL-2, THE SECOND MICROTRON USING A SUPERCONDUCTING LINAC[+]

P. Axel, L. S. Cardman, A. O. Hanson, J. R. Harlan, R. A. Hoffswell, D. Jamnik[*], D. C. Sutton, R. H. Taylor and L. M. Young
University of Illinois, Urbana-Champaign, Illinois U.S.A.

Summary

A second racetrack microtron, MUSL-2, is being assembled in the area previously occupied by the 300 MeV betatron. It uses a Van de Graaff to inject electrons at about 2 MeV, a 6 meter, 1.3 GHz superconducting linac made for us at the Stanford High Energy Physics Laboratory as the accelerating section and the magnets from MUSL-1 for recirculation[1]. A digital control console has been installed to operate the linac and the injection and recirculation systems. The CTI 1400 helium liquefier together with the low pressure heat exchanger from MUSL-1 maintains the linac at about 2 K. Beams of 10 microamperes with energies up to 14 MeV with a resolution of 0.2% are being used for nuclear experiments. Continuous beams up to 72 MeV will be available after the installation of the 6 pass system is completed.

Present plans for moving toward higher energies involve the use of MUSL-2 to inject electrons with energies up to 72 MeV into a second superconducting linac in a microtron operating at $\nu=1$. With return orbits separated by 7.35 cm relatively small magnets in the second system can accommodate 18 additional passes. At 12 MeV per pass electrons would reach a final energy of 288 MeV.

General Description

The arrangement of the components for MUSL-2 is shown in Fig. 1. An electron beam of about 2 MeV emerges from the vertically mounted Van de Graaff and passes through an achromatic 90° bend to the horizontal beam line. It is bent by 45° in the horizontal plane by another achromatic system and enters a pair of microwave choppers which moves the beam in an ellipse across a chopping aperture passing electrons within a phase spread of ±4°. It is turned through a 180° bend designed to keep the phase spread independent of small variations in the Van de Graaff energy as it enters the linac. The beam gains up to 12 MeV in the linac and enters the end magnet where it traverses a semicircle and is carried around the cryostat by the first bypass. It is turned around by the other end magnet and passes through the inflector chicane and into the linac for a second energy gain. The beam is guided through a second bypass and through three other return paths as can be seen in the figure. Magnets on various return lines can deflect the beams of different energies into the exit channel. The beam then passes through an energy analyzer which can be used to select the energy of the beam delivered to three experimental areas.

MUSL-2 Components

Although some of the components assembled in our second arrangement have been described elsewhere it may be useful to call attention to their present application and to proposed developments which can improve the performance of MUSL-2 as an accelerator facility.

Electron Injector

An injection energy around 2 MeV is desirable so that the beam does not drift out of phase in its first pass through the linac even if the energy gain is very low. It is also useful to have an injection energy which can be adjusted to maintain a constant ratio between the momenta of the first and second return beams. A surplus model KN3000 Van de Graaff with modified instrumentation in the high voltage terminal is used to supply bunched electron beams of 1.3 to 2.5 MeV. A corona current regulator keeps the energy stable to about ±2.5 keV.

Electrons originate at an electron gun, using a tungsten hairpin filament. It supplies a narrow electron beam at 40 keV. This beam passes down through a 1.3 GHz buncher cavity which modulates the energy of the beam so as to collapse an initial phase of ±60° to ±3° at the linac. As proposed in a previous report[1] the buncher was to be followed by a uniform magnetic field in which the beam is bent 180° to an energy defining slit which passes the collapsing beam and bends it by another 180° to its initial direction. Bench tests of this system, however, were not satisfactory and it was not installed in the terminal.

The beam emerges from the Van de Graaff and passes downward through a 45° bend followed by a quadrupole and another 45° bend making up a 90° achromatic bend onto the horizontal plane of the injection transport system. (The quadrupoles and other devices on the beam lines are not shown in Fig. 1.) The beam makes another achromatic bend of 45° and passes through the microwave choppers, which selects a phase interval of around ±4°. The chopped beam traverses the isochronous 180° bend into the linac. Near the entrance to the linac the chopped beam traverses a passive 1.3 GHz cavity which is used to monitor the amplitude and control the phase of the injected bunch.

Microwave Electronics

The microwave system is similar to that used in MUSL-1 in which the phase reference for the system is locked to the signal from a sampling probe in the accelerator section. The phase in the chopper cavities is controlled directly with respect to the reference signal. The phase in the buncher cavity in the high voltage terminal cannot be sampled directly but is determined by the signal generated by the bunched beam as it passes through a resonant cavity on the injection line. This phase is compared with the reference and the D.C. error signal is transmitted to the Van de Graaff terminal via a light link to adjust the phase of the buncher oscillator. Without specially selected components the buncher has a residual phase noise of ±2°. We hope to reduce this noise by an order of magnitude by transmitting a 1.3 GHz reference signal directly to the terminal.

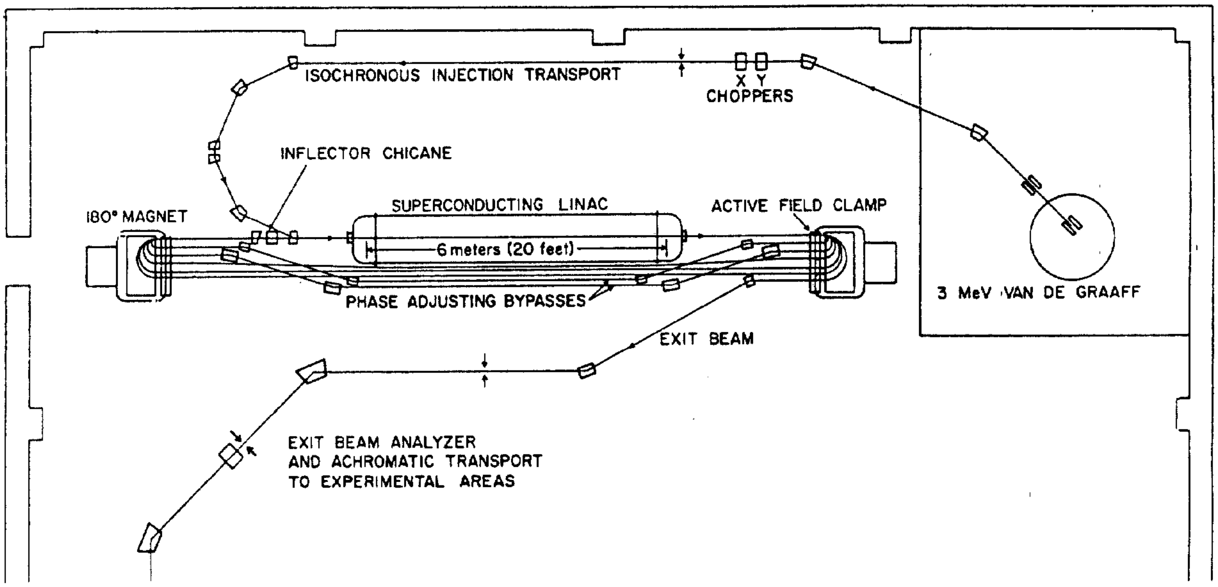

Figure 1. Arrangement of Components in MUSL-2. The quadrupoles and other elements are not shown.

Superconducting Linac

The initial test on the Stanford 6 meter section indicated that it could sustain energy gains up to about 13 MeV with about 10 watts of microwave power[1] corresponding to an unloaded Q of $3x10^9$. The connections to the closed cycle refrigeration system were completed in September 1976 and the linac has been covered with helium at about 2 K almost continuously since that time. In a recent run with the structure covered with liquid helium at 2 K a CW electron beam of 1.85 MeV was accelerated to a maximum energy of 14.75 MeV for an energy gain of 12.9 MeV with 10 watts of microwave excitation. This is essentially the same as its initial performance two years ago. The energy gradient is 2.3 MeV/m which is somewhat below that obtained from some 6 meter sections at Stanford.[2] The limiting energy seems to be associated with x-rays produced with no injected electrons. These begin to be detected outside the cryostat at 11 MeV and increase to 12 mR/hr at the limiting amplitude of 13.1 MeV.

The starting current for beam blowup in this particular linac has been estimated by the Stanford group to be about 50 microamperes for a single pass beam with an average energy around 8 MeV. This starting current could be reduced by a factor as high as the square of the number of passes if the blowup modes in the structure are excited coherently. A preliminary investigation[3], however, has indicated that such coherence could be much reduced by introducing weak transverse focusing on individual return lines.

Recirculation System

Much of the hardware associated with MUSL-1 will be used to recirculate the beam through MUSL-2. The small size of the yokes in these magnets limits the magnetic field to 5500 gauss. This corresponds to a maximum energy gain per pass at $\nu=2$ of 12 MeV which is a reasonable match to the energy gain available from the superconducting linac. The system is changed from that of MUSL-1 primarily by the two new phase adjusting bypasses as indicated in Fig. 1. Each consists of a set of four 18° deflecting magnets and four quadrupoles in a plane which is tilted downward by 15° so as to lie below the other return lines. The distance of the bypass line from the cryostat is mechanically adjustable to compensate for phase lags at various energies of the return beams.

An arrangement of components has been found which gives an overall transfer matrix which closely approximates a unit matrix. It is expected that the freedom to adjust the phases of the first two return beams will make it possible to obtain a continuous range of energies from the MUSL-2 system. The components for these bypasses are being installed at the present time. The recirculation system is expected to be complete by June 1977, capable of delivering a beam up to an energy of 72 MeV.

Beam Exit System

The recirculation system of MUSL-1 provides a means for deflecting the beam to the exit line after any number of passes. A high priority was placed on the design and construction of an exit system which provides a precision beam energy selector and achromatic transport line to experimental areas. As shown in Fig. 1 a beam from the 6th return pipe or any other return pipe is translated to the entrance slit of a 45° analyzer which transmits only that part of the beam allowed by the energy defining slits. In a particular experiment about 90% of the beam was passed through 1 mm slits having a resolution of 0.1%. The subsequent quadrupole and 45° magnet completes a 90° achromatic bend. This exit system and a transport line to an experimental resonance fluorescence area have been operative since July 1976 and have served to evaluate the performance of the MUSL-2 one pass system before MUSL-1 was disassembled. A 150 foot beam line to the previous tagged photon area is now complete. An extension to a second high resolution tagged photon facility and to a 200 MeV/c electron spectrometer are under construction.

Accelerator Control

The operation of MUSL-2 and the associated beam monitors and transport lines involves the monitoring and control of more than 100 magnets, steering coils, view screens, and other devices. With MUSL-1 all the monitors and controls were brought separately to the operators console. The placement of the MUSL-2 control console effectively 300 feet from the accelerator and the desire for greater reliability and versatility caused us to build a digitally operated control system.

The control panel which interfaces the operator to individual devices provides simultaneous control of up to 4 devices. The control information is transmitted serially in digital form to control areas near the accelerator and experimental areas where digital to analogue converters set the voltage references which control the currents in many magnets and other devices.

The system is arranged to be operated through a PDP-11/40 computer which will simplify the operation and logging of the many digital controls. The computer will also expedite the control of a possible larger system with 24 or more passes.

Cryogenics

During the initial tests with the 6 meter linac it was handled as an experimental cryostat and was filled with liquid helium from portable 500 liter and 200 liter dewars through the safety vent line. A special closure on the other end provided temporary connections to the liquid nitrogen shield supply and a 3 inch diameter plastic pipe to a 325 CFM vacuum pump in the Compressor Building. After installing a baffle inside the exit line to reduce heat transfer by convection the standby boiloff rate was just 3 liters of liquid helium per hour or about two watts.

After MUSL-1 was disassembled in August 1976 the CTI 1400 helium liquefier and the low temperature heat exchanger associated with MUSL-1 was installed in a small building just outside the accelerator cave. The heat exchanger is mounted in a liquid nitrogen shielded sump which is joined to the linac cryostat by a 20 foot section of 10.75" O.D. liquid nitrogen shielded line. The refrigeration system is quite versatile in that it can be operated with 1, 2, or 3 60 SCFM compressors with or without liquid nitrogen precooling. When filling the cryostat two compressors are used without liquid nitrogen precooling which add about 8 liters of liquid helium per hour to the cryostat at 2^{o}K. Once enough liquid has been collected one compressor can provide for the standby heat loss of the system, which is about 10 watts, and add 1 or 2 liters of liquid per hour. When a heat load of 10 watts is added to the cryostat it will lose 1 or 2 liters per hour. The cooling capacity of the system at 31 torr has been limited to about 20 watts by the 325 CFM capacity of the vacuum pump. The system operates almost continuously with no adjustments or attention other than routine maintenance.

Plans

As a step toward higher energy we hope to inject the beam from MUSL-2 into a second microtron (MUSL-3) in a cascade arrangement similar to one proposed by Herminghaus et al.[4] A schematic arrangement is indicated in Fig. 2.

A second superconducting linac is being made for us at Stanford University which will be available by mid 1978. It would be operated in a microtron arrangement with ν=1 having return orbits separated by 7.35 cm. By injecting at an energy of 72 MeV and gaining another 12 MeV on a pass through the linac the first return trajectory will be a straight line past the cryostat. Since we will have no injection chicane, no bypasses and a simpler exit channel, the recirculation system can be more compact. In order to

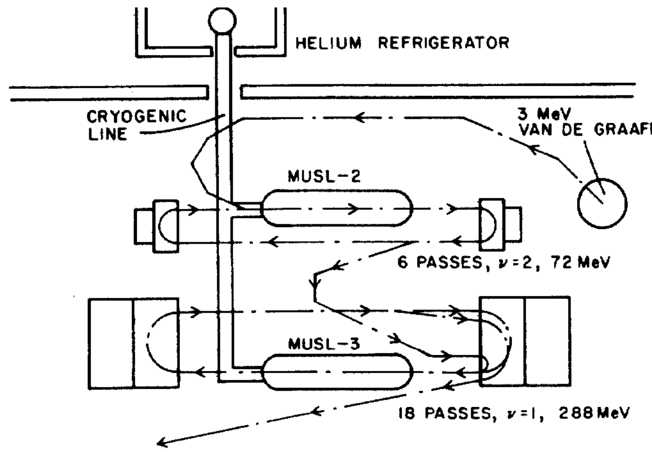

Figure 2. Proposed Cascaded Microtrons

move quickly and to significantly higher energies we are considering using economical magnets with pole pieces 1.8 by 0.9 meters which can accommodate 18 additional passes. With an energy gain of 12 MeV per pass this magnet would permit us to reach a final energy of 288 MeV. The high injection energy alleviates concern about beam blowup and a current of 10 microamperes should be available without any special arrangements. The continuous beams at the higher energy will be particularly useful in electron excitation experiments in which nuclear decay particles are observed in coincidence with inelastically scattered electrons.

In order to reach our original goal of 600 MeV at 12 MeV per pass we would require end magnets which could accommodate a nominal 50 passes. Such magnets would have pole pieces covering an area of 3.6 meters by 1.8 meters and each would weigh about 500 tons. The field strength required in this case is only 1.09 teslas and one can use very economical iron and simple assembly methods. With a magnetic field of 1.46 teslas the magnets could accommodate an energy gain of 16 MeV per pass for a final energy of 800 MeV.

Acknowledgements

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*Permanent address, Institute Josef Stefan, Ljubljana, Yugoslavia.

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