NBS-LANL RTM INJECTOR INSTALLATION

M.A. Wilson, R.I. Cutler, E.R. Lindstrom, S. Penner, N.R. Yoder, R.L. Ayres and D.L. Mohr
National Bureau of Standards
Washington, DC 23034

L.M. Young and E.R. Martin
Los Alamos National Laboratory
Los Alamos, NM 87545

Introduction

The injector for the NBS-LANL cw racetrack microtron (RTM)[1] consists of a 100 keV electron gun and beam transport line followed by a 5 MeV linac. The function of the gun and transport line, which have been installed at NBS, is to provide a chopped and bunched, 100 keV, and up to 0.67 mA dc or pulsed beam of very low transverse emittance (<5π mm-mrad) for matched insertion into the linac. In this paper we present both design and construction details of the 100 keV system and the results of preliminary beam tests. The tests conducted thus far show the gun and transport system to be performing well within design specifications.

Description

Electron Gun

The electron gun, shown in Figure 1, was designed and built by a vendor to the specifications given in Table 1.

Cathode potential:	-100kV operating, 120kV maximum
Cathode type:	Tungsten dispenser
Cathode diameter:	2mm, active area
Modulating electrode hole diameter:	2mm
Modulating electrode voltage:	-250V to +250V
Anode diameter:	4mm
Maximum current:	5mA
Beam quality:	At 5 mA, at least 4mA must be within an emittance ellipse area of 4π mm-mrad at 100 keV.
Pulse length:	<40n FWHM
Pulse rise and fall time:	<10n 10% to 90%
Pulse repetition rate:	100 kHz, maximum, continuously variable from external trigger source.

TABLE I. Electron gun specifications

The voltage applied to the modulating electrode (Figure 1) controls both the pulse and dc current levels produced in the gun. The pulse capability of the gun will be used for tune-up and diagnostic purposes in the RTM, which will, otherwise, be operated in the cw mode. The large cylindrical electrodes shown in Figure 1 shape the 100 kV accelerating field to provide focusing of the electron beam emerging from the gun. The grounded shield electrode is necessary to prevent beam steering and distortion effects due to charge build-up on the insulator.

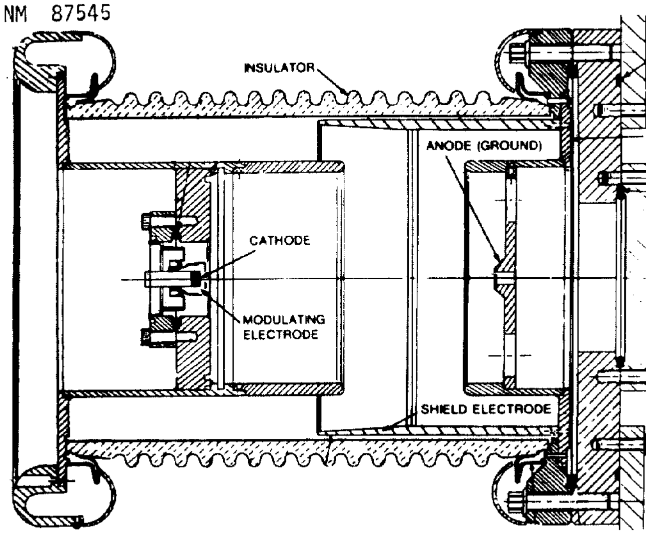

FIG. 1. Electron gun cross section.

A high voltage terminal (HVT) houses the gun control electronics and is connected to the gun cathode. A high voltage power supply maintains the HVT at -100 kV, stable to ± 100 V. Figure 2 shows the HVT and electron gun inside a grounded enclosure with one side removed for display. In addition, one side of the HVT has been removed to display the computer-based gun control electronics. These electronics consist of filament power supplies, programmable bias supplies (upper chassis) for both dc and pulsed operation of the gun, and a card cage containing a single-board computer (SBC), A/D and D/A boards linked to the filament and bias supplies, and a fiber-optics interface board. Control and monitoring of the gun parameters is routed through the SBC, where data are transmitted digitally in bit serial form over fiber-optic cables to/from the injector secondary station, the next level in the RTM computer-based control system.[2] In addition to compatibility with a computer-based control system, this use of a micro-computer and light links provides for simple, reliable flow of control and status information across a high potential without the need for insulating rods, stepping motors and T.V. monitors. Figure 3 is a simplified schematic of the control system for the 100 keV electron beam. Note that the injector secon-

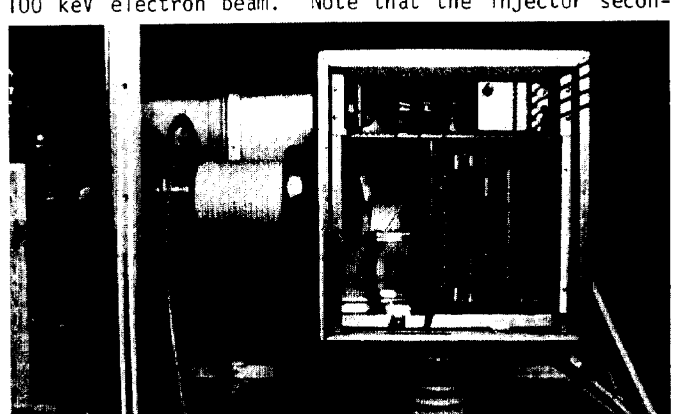

FIG. 2. Photograph of electron gun and high voltage terminal within the grounded enclosure.

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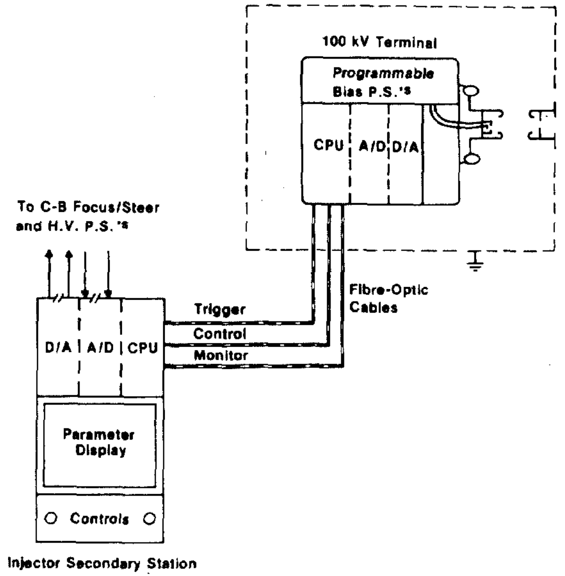

FIG. 3. Schematic of computer-based control system for 100 keV electron beam.

dary station also controls the currents in all the steering and focusing elements in the 100 keV beam line.

100 keV Beam Line

The function of the 100 keV transport line, whose elements are shown schematically in Figure 4, is to chop, bunch and limit the transverse emittance of the beam from the electron gun. At the point of insertion into the capture section of the 5 MeV linac, the design beam parameters are as given in Table 2.

Transverse emittance:	<5π mm-mrad at 100 keV
Beam diameter:	6mm, converging
Longitudinal emittance:	5π keV-deg
Longitudinal phase spread:	14 deg, full width
Beam current, dc:	0.67 mA

TABLE II. Design values of 100 keV beam parameters at the point of insertion into the 5 MeV linac. Emittances are defined as the area of the smallest ellipse enclosing 90% of the beam. An emittance of <4π mm-mrad has been defined at the entrance to the chopper system.

The optics was designed using the program, BEAMRAD (developed at NBS), which solves a cylindrically symmetric beam envelope equation with space charge and external focusing and accelerating fields. Figure 5 is a plot of the computed beam envelope radius as a function of position along the beam line. Referring to Figures 4 and 5, the beam enters the system through the 4 mm diameter gun exit aperture and is aligned to the system with steerers, S_1 and S_2. Solenoid lens, L_1, is used to produce a beam waist at the 1.6 mm diameter aperture, A_1. A_1 and the 8 mm diameter aperture, A_2, together define the emittance of the transmitted beam to be no greater than $E_T = 4\pi$ mm-mrad. Steerers, S_3 and S_4, assure alignment of the beam through the chopper-buncher section. The lens, L_3, focuses the transmitted beam through the 1 mm diameter central hole in the chopper aperture, A_3. Lenses, L_5 and L_6, are adjusted for transverse matching of the beam into the capture section of the 5 MeV accelerator.

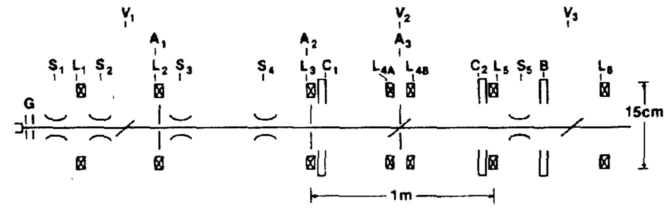

FIG. 4. Schematic of beam optic elements on the 100 keV beam line. Note the difference between x and y scales in the drawing.
S - steerer
L - focus lens
V - viewscreen
A - aperture
C - rf deflecting cavity
B - rf buncher cavity

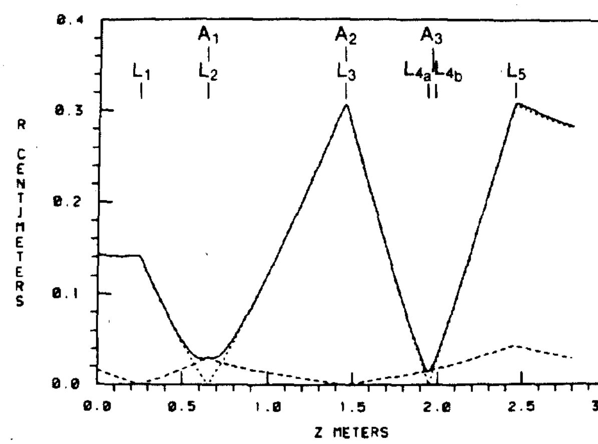

FIG. 5. Computed beam envelope radius along 100 kev beam line. The dashed lines are single rays used to locate object and image points.

When the rf deflector cavities, C_1 and C_2, are driven correctly in phase and amplitude, the transmitted beam is chopped into segments each occupying only 60° of the longitudinal phase along the beam transport axis, with a corresponding reduction of the average beam current from 4 mA to 0.67 mA. The chopper-buncher system is driven at the same frequency (2.38 GHz) as the accelerating sections and is phased for optimum insertion. The system has been designed to make a negligible contribution to the transverse beam emittance during chopping. During this process the beam centroid follows a path indicated schematically by the dark line in Figure 6a. The beam is deflected off axis by transverse rf fields in cavity, C_1, such that the deflected beam rotates about the beam line in a circular motion with an amplitude of 1 cm diameter at the

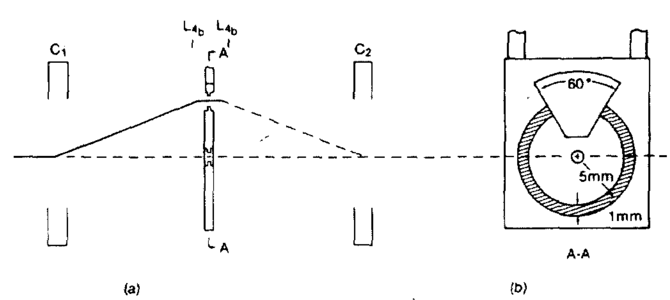

FIG. 6. (a) Schematic representation of beam manipulations by chopper-buncher system. (b) Schematic front view of chopper aperture with circularly rotating beam sweep (hatched area).

chopper aperture (Figure 6b). A 60° slot in the chopper aperture assembly allows a portion of the deflected beam occupying 60° of longitudinal phase space to be transmitted. The lens pair, L_{4a} and L_{4b}, is adjusted to deflect the beam centroid toward the beam transport axis such that the beam crosses the axis at the rf cavity, C_2. The fields in C_2 are adjusted in amplitude and phase relative to C_1 so that the beam is redeflected along the transport axis. The buncher cavity (B in Figure 4) applies an rf field to the beam: The buncher rf is phased with the chopper rf such that the beam is gently compressed in longitudinal phase to about 14° by the time the bunch reaches the capture section. Viewscreens V_1, V_2, and V_3 (Figure 4) are used to guide the operator in performing beam manipulations. Beam steerers are commercially available T.V. magnetic deflection yokes. Figure 7 shows a schematic cross section of a typical focus lens, developed at NBS and consisting of a pancake solenoidal winding encased in a mild-steel housing. All apertures are water-cooled and electrically isolated to provide beam current information. Figure 8 is a photograph of the beam transport and chopper-buncher system. All but the final section of magnetic shielding have been removed for a better view of the components. This envelope of mu-metal sheet was designed to enclose the beam line as much as possible to prevent deflection and distortion effects on the beam due to stray fields in the room.

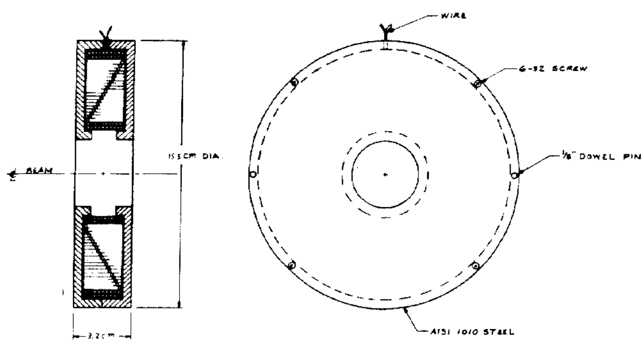

FIG. 7. Schematic of solenoid focus lens

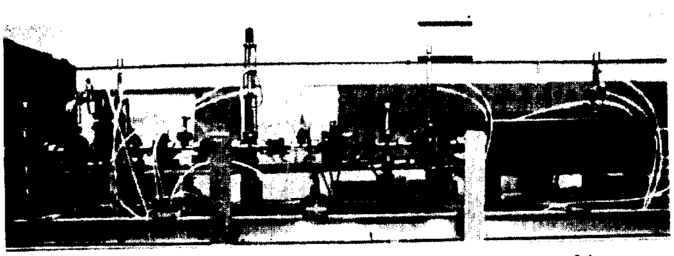

FIG. 8. Photograph, side view, of 100 keV beam line.

100 keV Beam Line Status and Test Results

Installation of the beam line is complete with the exception of the chopper aperture, buncher cavity and rf position detector. The 3.5 m beam line presently terminates in a water-cooled Faraday Cup. The gun, focus elements, apertures and rf cavities have been aligned on a common axis to within ± 0.15 mm. Vacuums better than 1×10^{-8} Torr in the beam line and 5×10^{-9} Torr in the gun have been routinely achieved.[3]

The electron gun and high voltage terminal have been tested up to 118 kV with only moderate conditioning required. DC beams over 5 mA have been produced by the gun at 100 keV. The system requirement of at least 4 mA dc and pulsed transmission through the emittance defining apertures, A_1 and A_2, has been achieved. Figure 9a shows a 45 ns, FWHM, "notch" in a 4 mA dc beam emitted from the gun at 100 keV. This notch was produced by pulsing the dc bias off. Figure 9b shows the result of focussing a pulsed electron beam through apertures, A_1 and A_2. 4.0 mA is transmitted, while less than 1.0 mA is scraped off on the apertures.

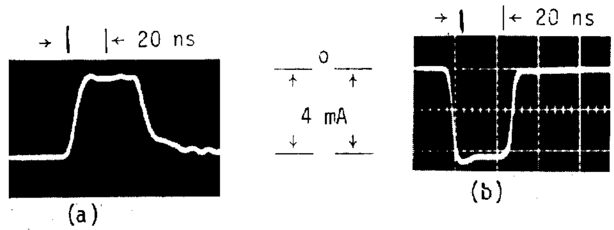

FIG. 9. (a) 35ns (FWHM) "Notch" in 4mA d.c. electron beam produced by pulsing d.c. bias off. (b) Electron beam pulsed on. The 4.0mA 30ns FWHM trace is the current collected on viewscreen #3 nearly 3m from the gun.

During the beam tests, the effects of unwanted stray fields on the electron beam were studied and care was taken to minimize these fields in order to maintain the high beam quality necessary for a fully successful RTM. It was found that fields with significant effect on the beam were being produced inside the magnetic shield by presumably non-magnetic beam line components. An example of these stray field effects is shown in Figures 10a, 10b, 10c. In Figures 10a and 10b a high (> 6 mA) pulsed, drifting (unfocused) beam is shown incident on viewscreens #1 and #2, respectively. Apertures, A_1 and A_2, were removed for this study. The beam cross section is severely distorted by a high gradient field before the second viewscreen. Figure 10c is the beam spot on viewscreen #2 after de-gaussing of an "all-stainless" valve on the beam line near the first viewscreen. All such distorting fields have been reduced to a tolerable level.

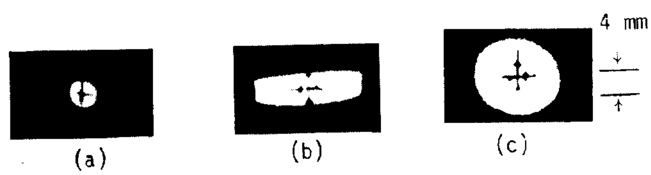

FIG. 10 (a) Image of 6mA drifting pulsed beam on first viewscreen (60 cm from gun). (b) Same beam at second viewscreen, 150 cm further along beam line. Note distortion. (c) Same beam at second viewscreen after degaussing beam line valve.

Transmission of a well-focused beam of over 4 mA through the emittance defining apertures, A_1 and A_2, and onto viewscreen #3 (Figure 11) completes the performance tests of the electron gun and beamline steering and focussing.

FIG. 11 Image of 4mA pulsed beam at third viewscreen, having passed through emittance defining apertues.

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