PERFORMANCE OF THE 5 MeV INJECTOR FOR THE NBS-LOS ALAMOS RACETRACK MICROTRON*

M.A. Wilson, R.L. Ayres, R.I. Cutler, P.H. Debenham, E.R. Lindstrom,
D.L. Mohr, S. Penner and J. Rose
National Bureau of Standards
Gaithersburg, MD 20899

L.M. Young and J. Stovall
Los Alamos National Laboratory
Los Alamos, NM 87545

Introduction

The NBS-Los Alamos racetrack microtron (RTM) injector consists of a 100 keV chopper/buncher system and a 5 MeV, 2-section, side-coupled, continuous wave RF linac operating in a standing-wave mode at 2380 MHz. The purpose of the injector is to provide a low-emittance electron beam of up to 550 μA CW current, with a suitably small phase and energy spread for insertion into the RTM.

Measurements have been made of the injector beam energy, energy spread, and transverse emittance over a range of beam current from 150 μA to 600 μA and at beam energies of 4.08 MeV, 5.05 MeV, and 5.50 MeV. The measured, normalized, transverse emittance, averaged over beam current and energy is $\varepsilon_{nx} = 0.55$ mm-mrad and $\varepsilon_{ny} = 0.71$ mm-mrad. These results indicate a beam quality considerably better than the design goal of 5.0 mm-mrad. The measured beam energy spread, ΔE, is 5 keV at 5 MeV and appears relatively independent of beam current. Although measurements of the beam phase spread are incomplete, preliminary results suggest the longitudinal emittance is no greater than 5 keV-degrees, which is well within the design goal of 20 keV-degrees.

Accelerator Description

The RTM injector (Figure 1) begins with a 100 kV 5 mA dc electron gun followed by a chopper/buncher system[1] which chops the beam into 60° phase intervals at the RF frequency, followed by compression to 10° at the entrance to the capture section of the injector linac. The tapered-β capture section, which accelerates the 100 keV electron beam to 1.3 MeV, is followed by the stepped-β preaccelerator which increases the beam energy to 5 MeV for injection into the RTM. In the RTM[2], the electron beam is recirculated through a 12 MeV linac up to 15 times, achieving an energy of up to 185 MeV. The design of the RTM requires an injected beam of high quality for minimum beam loss and for the production of an extracted beam suitable for such applications as a free electron laser driver. Achieving this injected beam quality has required careful alignment of the beam through all focusing and accelerating elements, matching of the beam envelope at the accelerator sections, and reduction of stray magnetic fields. In addition, the increase in transverse emittance caused by field gradients in the RF chopper deflecting cavities[3] has been minimized by minimizing the beam size in the cavities.

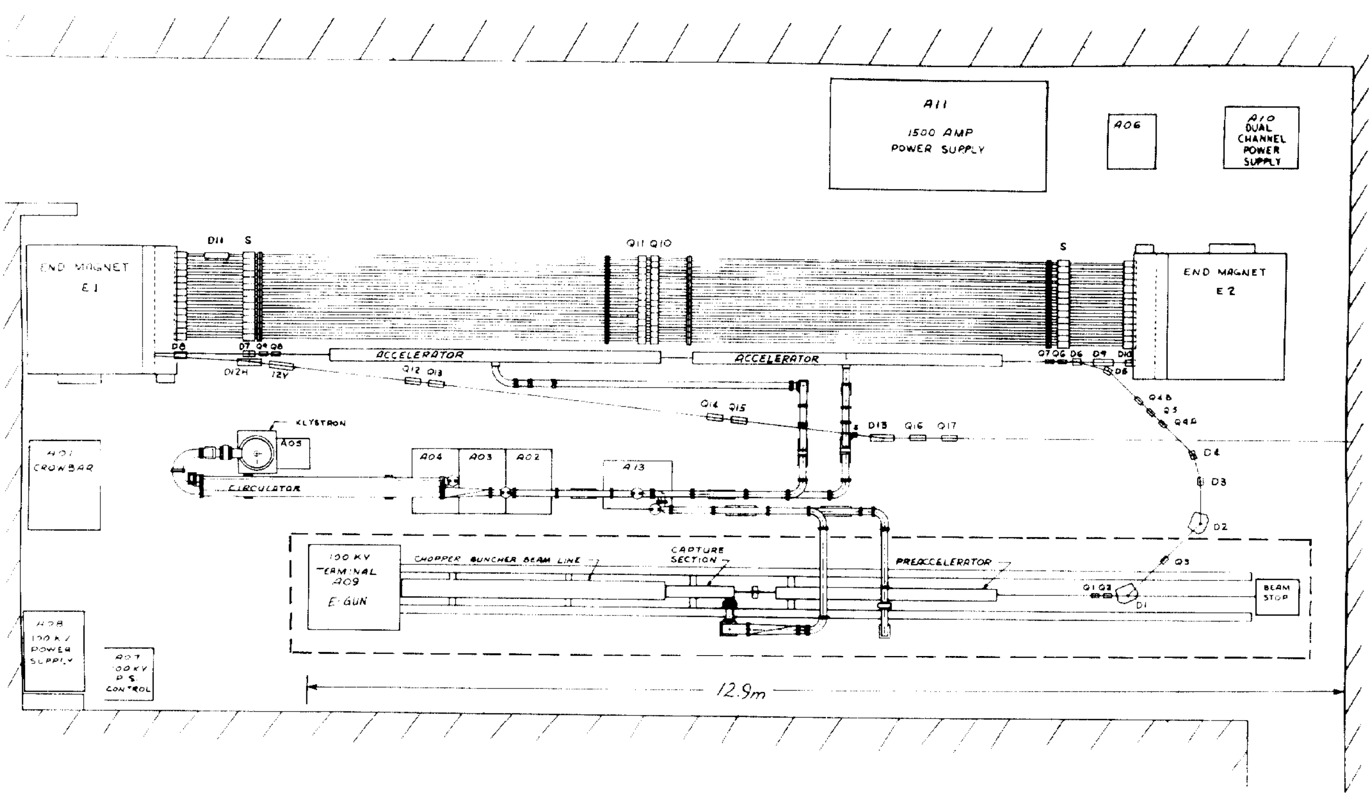

Figure 1. Top view of the NBS-LANL racetrack microtron. The injector is enclosed by the dashed line.

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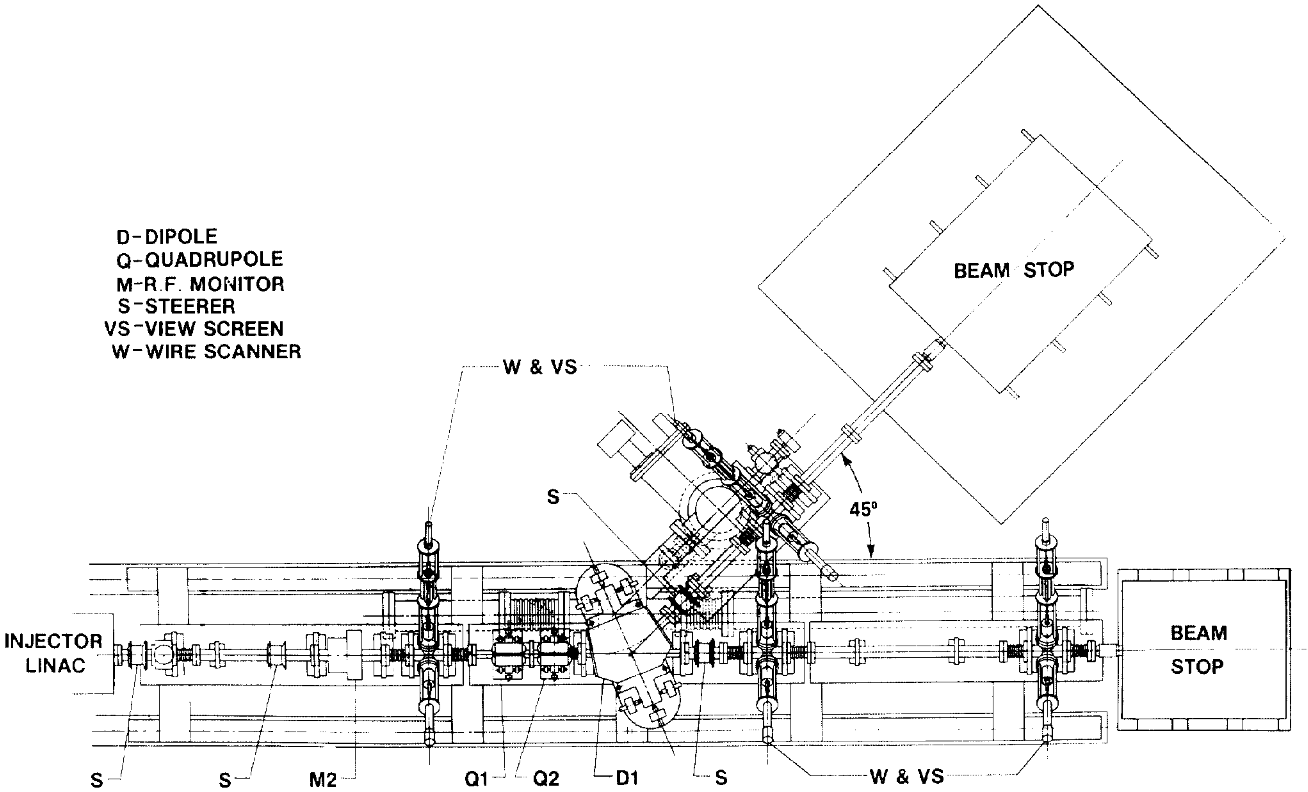

Figure 2. Top view of the beam line at the exit of the 5 MeV linac, showing the locations of the view screens, wire scanners and 45° bending magnet, D1. The spacing between wire scanners on the linac axis is approximately 1 m.

Beam Measurements

Beam measurements have been made to establish the 6-dimensional phase space of the electron beam of the injector linac and to optimize the beam parameters for insertion into the RTM. This was accomplished by determining the location of the accelerated beam waist and the beam divergence from a sequence of beam profile measurements and by measurement of the beam energy and energy spread. The beam line at the exit of the injector linac (Figure 2) contains view screens and wire scanners for observing the beam profile at three positions along the linac axis and one position on the 45° beam line. View screens are used for qualitative beam shape and size estimates and for beam alignment. For precise beam size measurements a wire scanner[4], employing a reciprocating 30 μm diameter carbon filament, is used. The beam profile (shown for the horizontal beam axis in Figure 3) is produced by recording the wire

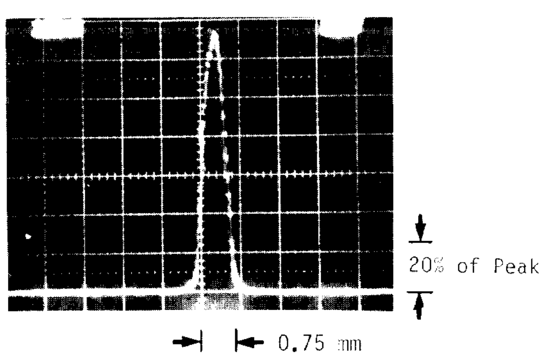

Figure 3. An oscilloscope trace of the beam profile produced by a wire scanner on the emittance measurement line.

position vs current on the wire on the x- and y-axes, respectively, of an oscilloscope.

To minimize the effect of baseline noise, the beam size is defined as the full trace width at 20% peak height. For most of the transverse current density distributions encountered in this study, this assures that at least 95% of the beam is included in the defined envelope.

Emittance Measurements

Beam size measurements from the three wire scanners on the injector linac axis (Figure 2) are used to determine the transverse emittance of the accelerated beam. The transverse geometric emittance is defined by:

$\varepsilon_x = X_0\theta_0$ (similarly for ε_y), where:

X_0 = beam radius at the beam waist and θ_0 = maximum angular divergence of the beam at the waist. X_0 and θ_0 are found from the size measurements using the following relations for a drifting beam:

$X_i^2 = X_0^2 + (Z_i - \Delta)^2\,\theta_0^2$, i = 1, 2, 3, where:

X_i = beam radius at axial location Z_i, and Δ = location of waist (selected, for measurement accuracy, to be near Z_2).

To express the beam transverse emittance independently of beam energy, the normalized emittance is defined:

$\varepsilon_{nx} = \beta\gamma\,\varepsilon_x$, where β is the ratio of the beam electron velocity to the velocity of light and γ is the ratio of electron total energy to the electron rest energy. All measured emittances quoted in this paper represent approximately 95% of the total beam current.

Figure 4 is a plot of the normalized measured transverse emittance, ε_{nx} and ε_{ny}, of the injector electron beam over the range of beam current from 150 μA to 600 μA, CW, at 5MeV. There does not appear to be any systematic relation between beam current and emittance. In addition, the transverse beam emittance was measured at 4.08 MeV and 5.5 MeV, with no obvious relation between normalized emittance and beam energy. The values of the normalized transverse emittance averaged over all the measurements are ε_{nx} = 0.56 ± 0.10 mm-mrad and ε_{ny} = 0.70 ± 0.17 mm-mrad. This measured beam quality is considerably better than the design goal of 5 mm-mrad. Earlier measurements of the 100 keV beam resulted in normalized emittances of: ε_{nx} = 0.47 mm-mrad and ε_{ny} = 0.55 mm-mrad. Therefore, acceleration to 5 MeV contributes about a 20% growth to the beam emittance. The prediction by the computer program PARMELA, for calculations of electron beam transport through the injector linac, is a normalized emittance of ε_{nx}= 0.75 mm-mrad for 90% of the beam particles after acceleration to 5 MeV, starting with the calculated gun emittance of 0.6 mm-mrad.[5]

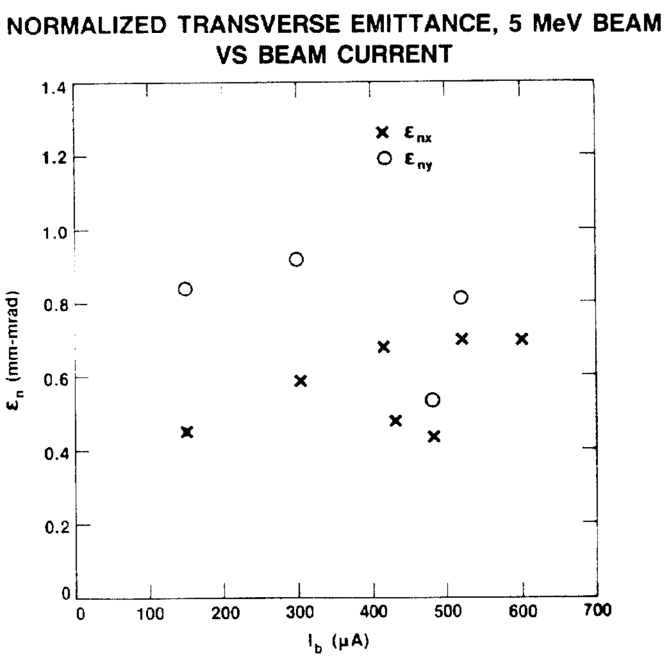

Figure 4. Normalized transverse beam emittance at 5 MeV, plotted vs beam current.

Energy Spread Measurements

To measure the beam energy and energy spread, the accelerated beam is first deflected through 45° by the dipole magnet, D1, (Figure 2). The deflected beam is then detected by either a wire scanner or view screen inserted at the exit focal plane of D1. The beam energy is determined from the magnetic field required to bend the beam through 45°. The beam envelope width in the plane of the bend is measured with the wire scanner (Figure 5). The beam energy spread is then determined from the measured envelope width and the known dispersion of the magnet. Corrections due to finite beam size and divergence are less than 5% of the energy spread.

The energy spread of the beam accelerated to 1.3 MeV by the capture section was first minimized as a function of the capture section RF phase. Then the energy spread of the beam accelerated to 5 MeV was minimized with respect to the preaccelerator phase. In addition, the buncher power was adjusted for the minimum energy spread in the accelerated beam. The resulting minimum energy spread was measured to be:

ΔE = 5.3 keV at 4.08 MeV
= 5.1 at 5.05 MeV
= 4.4 at 5.5 MeV

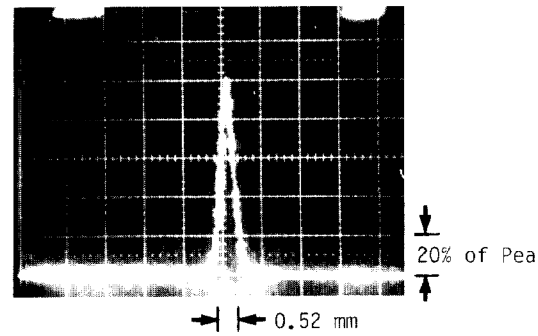

Figure 5. An oscilloscope trace of the horizontal beam profile produced by the wire scanner at the exit focal plane of the 45° dipole magnet, D1. The trace width at 20% of peak height corresponds to an energy spread of 5.6 keV.

These results are somewhat smaller than the predictions by PARMELA, which calculates an output full energy spread of 10-15 keV at a full phase spread of about 2 degrees.

Conclusions

Measurements have been made of the transverse emittance and energy spread of the electron beam from the injector accelerator for the NBS-Los Alamos RTM. The results indicate a beam quality considerably better than design goals.

Measurements of the beam phase spread are incomplete. It is anticipated that these measurements will establish the optimum operating parameters of the injector accelerator and result in possible further improvements in beam quality. Preliminary measurements suggest that the longitudinal emittance is approximately a factor of 5 better than the design goal.

References

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[2] S. Penner, et al., Progress Report on the NBS-Los Alamos Racetrack Microtron, IEEE Trans. Nucl. Science, NS-32, No. 5, (October, 1985) p 2669.

[3] J. Haimson, Optimization Criteria for Standing Wave Transverse Magnetic Deflection Cavities, Proceedings of the 1966 Linac Conference, LA-3009, Oct. 3-7, Los Alamos, NM, p 303.

[4] R.I. Cutler, et al. Performance of Wire Scanner Beam Profile Monitors to determine the Emittance and Position of High Power CW Electron Beams of the NBS-Los Alamos Racetrack Microtron, this Conference Record.

[5] R. Miller, Stanford Linear Accelerator Center, results of EL CIDITO Gun Code, private communication.