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# 185-MeV INJECTOR DESIGN FOR THE ANL 4-GeV MICROTRON PROJECT*

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## Summary

The injector starts with a 5 MeV preinjector followed by an 18 MeV S-band linac. The 23 MeV electrons are transported and injected into a Racetrack Microtron via a 10° achromatic bend system. Twenty-seven turns are used to boost the energy to 185 MeV. Reverse-field stripes on the 180° end magnets and quadrupole focussing on the return paths maintain a matched-dispersion free beam with transverse $\beta^* = 5.0$ m in the center of the 4.6 m long linac. The beam is recirculated outside of the RTM linac to shear the longitudinal phase-space ellipse before extraction. The extracted beam is transported and injected into the six-sided microtron at 185 MeV.

## Introduction

The Argonne proposal for a 4-GeV electron accelerator consists of a six-sided microtron (the hexatron) utilizing three 35 MeV linacs and three dispersive straight sections.[1] The constraint of placement of the machine in the ZGS ring building imposes severe restrictions on the structure and location of the associated injector, which is the subject of this report. The major requirement is to accelerate a 100 keV electron beam up to 185 MeV kinetic energy; the resulting beam must be matched into the acceptance of the hexatron with minimal losses. The injector must provide a microstructure that may produce three independent beams of different energy and flux. Figure 1 shows a plan view of the injector.

The basic scenario is described: (i) the 100 KeV electrons are passed through chopper, prebuncher, a system of cavities and slits for producing three bunches of different fluxes. A capture section and preaccelerator take the electrons to 5 MeV. (ii) eight 2.27 m on-axis cavities operating at S-band accelerate the beam up to 23 MeV kinetic energy; (iii) a Racetrack Microtron (RTM) accelerates the beam to 185 MeV in 27 turns; (iv) the beam is extracted, transported, and matched to the hexatron; this section utilizes quadrupoles, dipoles, an rf cavity, and possible 1/3 subharmonic buncher that slightly shifts the energy by ± ΔE for two out of three bunches. We discuss these procedures below.

## 5 MeV Injector to the RTM

The design of the 0-5 MeV preinjector is treated in reference 1 and appears there as Fig. III-3. The output of this preaccelerator should be matched to the periodic focussing structure that is used in the 18 MeV linac. The linac raises the beam kinetic energy to 23 MeV. The last element of the linac is a horizontally focussing quadrupole (QFA). The elements depicted in Fig. 1 between the 18-MeV linac and RTM dipoles steer the beam into the injection septum ($S_1$). This section matches the beam in the center of QFA to the conditions required at $S_1$--these are $\beta_x = 0.23857$ m, $\alpha_x = -0.52122$, $\beta_y = 28.99897$ m, and $\alpha_y = 8.65622$.[2] The injection is carried out using three septum dipole magnets on displaced orbits. Figure 2 shows the

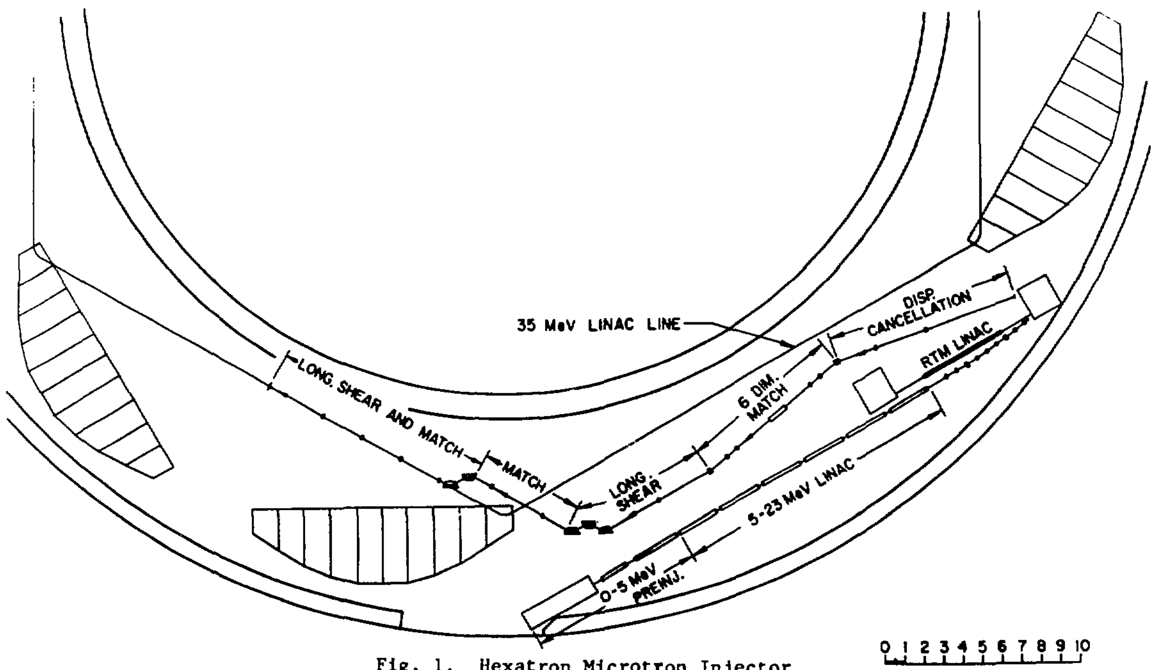


Fig. 1. Hexatron Microtron Injector

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plan view geometry of the designed syutem (actually a mirror image). The $S_i$ are all septum dipoles and the $Q_i$ are quadrupoles. The beam arriving at point A is bent 10° left by $S_1$, passed through a 180° bend in the RTM dipole and arrives at $S_2$ a distance d from the linac axis. The translation $S_2$-$S_3$ uses two 7.8436° bends and the exiting beam is displaced 2d (≡13.647 cm) from the linac axis. The second RTM dipole puts the beam on the linac axis for acceleration to 29 MeV. The quadrupoles Q1-Q5 are used for dispersion cancellation and focussing. The vertical focussing quadrupole $Q_D$ has a strength 0.3 $m^{-1}$ at 23 MeV.

## RTM Design

The plan view of the RTM is shown in Fig. 3. The beam is injected as explained above, and accelerated to 185 MeV in 27 turns. The linac acclerating field is 1.4 MV/m at an rf wavelength of 12.5 cm (S band). The central dipole field of B = 1.0T results in an orbit separation of ~4.0 cm between successive return paths. We have chosen a mode number = 1, synchronous phase $\phi_s$ = 20°, and synchrotron frequency $\nu_s$ = 0.27291. The RTM requires good quality optics in order to be used as a booster rather than a stand-alone machine. Thus, we require a matched $\beta^*$ = 5.0 m condition at the linac center with no dispersion. Earlier studies[2] indicate the five quadrupole containment system can meet the requirements (see Fig. 4). Furthermore, we intend to use reverse-field clamps in the RTM dipole fringe regions (see Fig. 3) as introduced by Babic and Sedlacek.[3] The expected orbits are as shown in Fig. 2. These clamps, when energized to a minimum field of -0.16 B, can completely neutralize the severe vertical defocussing due to the soft-edge RTM dipole fields.[1]

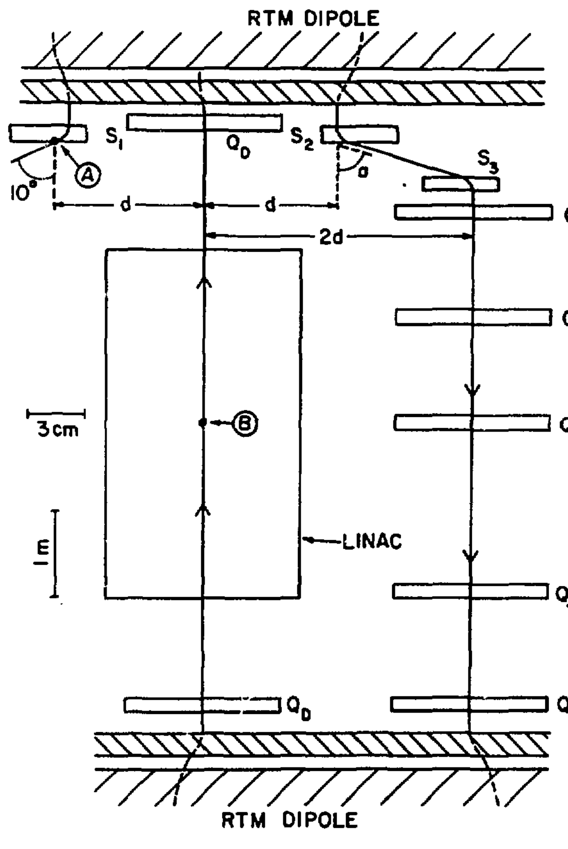


Fig. 2. Plan view of RTM injection components (actually a mirror image). The solid line represents the 23 MeV trajectory.

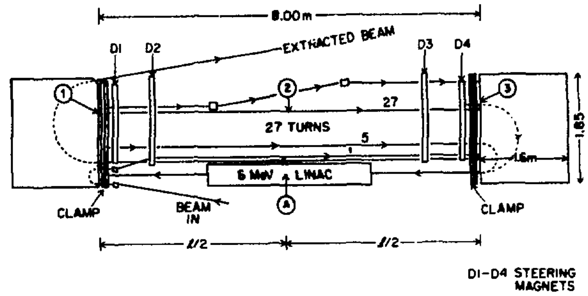


Fig. 3. RTM Layout showing injection and extraction techniques.

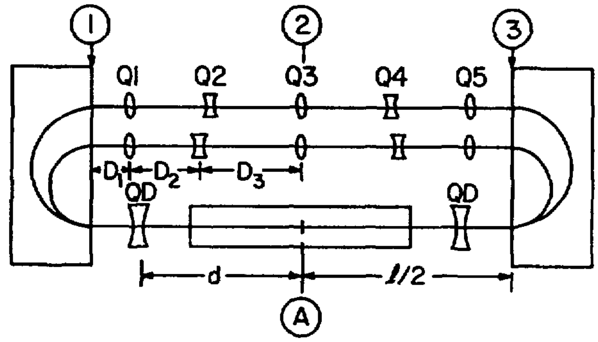


Fig. 4. RTM layout showing quadrupole focussing systems.

A thin-lens program was written to solve the equations of constraint, i.e., to produce beam waises at points A ($\beta_A^*$ = 5.0 m) and (2) along with a dispersion-free beam in the linac $\eta_A = \eta_A' = \eta_2'$ = 0. the energy dependences of the $\beta_y$ and $\beta_x$ are presented in Fig. 5 at three selected locations in the return path. We note that the optical system is mirror symmetric around Q3 so, e.g., (β in Q2) ≡ (β in Q4), etc. We also include the obtained quadrupole strengths in Fig. 5(c). The reader is referred to reference-1 for a more detailed description of the RTM design.

## RTM Extraction

The extraction procedure shown in Fig. 3 involves translating the last return path about 6 cm outwards and recirculating the beam one more time, but outside of the RTM linac. This procedure shears the longitudinal phase-space ellipse and aids in the longitudinal match between the RTM and hexatron. The final bend of 170° brings the beam out. Before the translation, the longitudinal matched beta is given by $\beta_i$ = 0.025965 deg/keV and $\gamma_i$ = 0. After passage through the translated orbit and extraction, we obtain $\beta_1$ = 0.16609 deg/keV, $\gamma_1$ = 38.51338 keV/deg and $\alpha_1$ = -2.32307 in the longitudinal $\phi$-W phase plane.

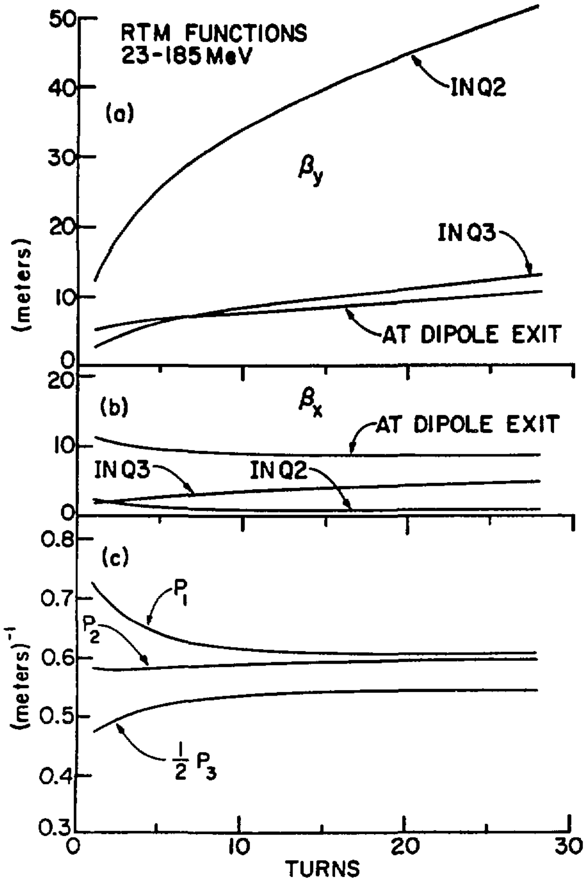


Fig. 5. (a,b) Behavior of $\beta_y$ and $\beta_x$ at indicated locations on the RTM return paths vs. turn number; (c) Quadrupole powers.

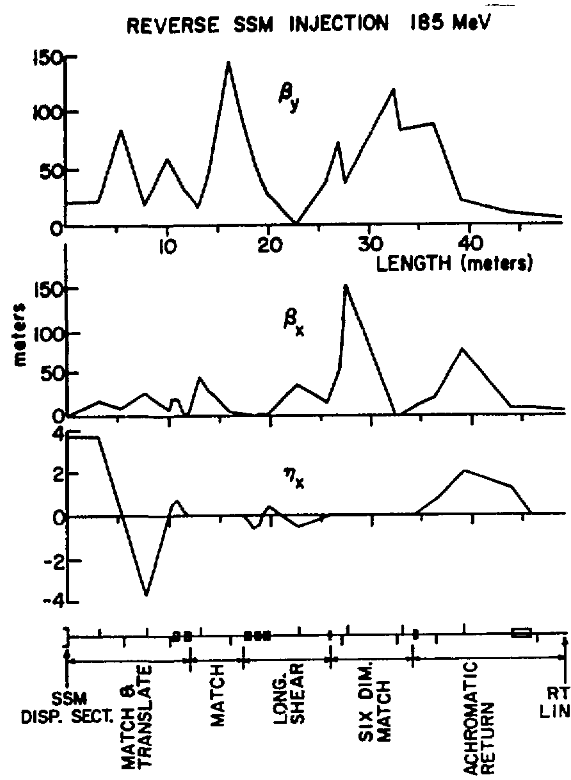


Fig. 6. Behavior of $\beta_y$, $\beta_x$, and $\eta_x$ through the reverse injection line from RTM to hexatron.

## Transport to the Hexatron

The match conditions at the center of the 185 MeV straight section of the hexatron are waists $\beta_x^* = 0.6$ m, $\beta_y^* = 19.9$ m, $\eta_x = 3.7$ m, $\eta_x' = 0$, in the transverse planes and a final $\beta_f = 3.79675 \times 10^{-3}$ deg/keV and $\alpha_f = 0$ in the longitudinal plane. The transport and matching system was designed in a modular fashion and consists of quadrupoles, dipoles and an rf matching cavity. The system consists of five sections: (i) dispersion cancellation, (ii) straight section #1 for transverse matching and location of an rf matching cavity, and subharmonic buncher (if utilized). (iii) achromatic bending section for longitudinal shearing, (iv) straight section #2 for transverse matchine, and (v) a final injection section implementing two dipoles for longitudinal shearing and quadrupoles for dispersion matching.

The rf matching cavity increases the longitudinal $\gamma$ value to the required value $\gamma_f = 1/\beta_f$ - the voltage required is about 1.4 MV. The beta function is assumed unchanged so the Twiss parameters at the end of section (ii), $\beta_2 = \beta_1$, $\gamma_2 = \gamma_f = 1/\beta_f$ and $\alpha_2 = -6.53797$. Beam sections (iii) and (v) introduce negative shears to the longitudinal phase-space ellipse so as to produce the desired upright ellipse with final $\beta_f = 3.79675 \times 10^{-3}$ deg/keV. Both the transverse and longitudinal matching were accomplished using the program TRANSPORT.[4] The entire system was designed in reverse order proceeding from the hexatron injection point back to the RTM extraction. The transverse Twiss parameters $\beta_y$, $\beta_x$ and dispersion trajectory $\eta_x$ are graphed in Fig. 6 as a function of position in the beam line; components and sections are indicated in the lower section.

## Conclusion

The design carried out here is valid to first-order. The small emittance $\varepsilon<0.2\pi$ mm-mr and energy spread $\Delta E/E \sim 10^{-4}$ justify this treatment. A future treatment should consider the chromatic terms that may become important if a subharmonic cavity is used for multiple energy extraction from the hexatron.

## References

1. See e.g., "A National CW GeV Electron Microtron Laboratory," Argonne National Laboratory Report ANL-82-83 (December 1982).

2. E. Colton, "New Transverse Focusing Schemes for the RTM," Argonne National Laboratory Report ANL-GEM-19-82 (1982, unpublished).

3. H. Babic and M. Sedlacek, Nucl. Instrum. Methods. 56, 170 (1967).

4. K. L. Brown et al., TRANSPORT, CERN-73-16 (1973).

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