A 10 MeV Injection Beam Transport Line for a Racetrack Microtron

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Abstract

The ion optical design of a beam transport line from a 10 MeV injector linac to a 10–75 MeV racetrack microtron is given. The bending section in the beam line consists of a two step doubly achromatic system to bring the beam down from the linac axis to the median plane of the microtron. This achromatic system comprises four identical 50 degree dipole magnets. A quadrupole triplet between linac and bend section and a quadrupole doublet with electron steering capability downstream the bends are also incorporated.

1 INTRODUCTION

The 400 MeV electron storage ring EUTERPE [1] is a university project set up for studies of charged particle beam dynamics and application of synchrotron radiation. The injection chain of EUTERPE consists of a completely revised 'old' medical 10 MeV travelling wave linac followed by the 10–75 MeV RaceTrack Microtron Eindhoven (RTME) [2] (see fig. 1).

For injection into the microtron the linac axis is placed approximately 40 cm above the median plane of the microtron. The electron beam is guided over one of the dipoles of RTME and then brought down to the median plane of the microtron with a two step doubly achromatic bending system (fig. 1). The geometrical and supplementary demands on the injection beam line are described in section 2. The doubly achromatic bending system is described in section 3. The bending system is preceded by a quadrupole triplet and followed by a quadrupole doublet in order to provide adequate focusing. Section 4 describes the ion optical design of the complete beam transport line.

2 DEMANDS

The existing design of RTME imposes geometrical constraints on the parameters of the injection beam line. The bridged height should be about 40 cm (the dipole rises ±22.5 cm above the median plane). The spanned length of the bending section must not exceed ± 67.5 cm. This to prevent the bending section from stretching out over the microtron dipole, as otherwise this would be inconvenient for possible demontation in future. Also this constraint clears space (~ 17 cm) for the quadrupole doublet between bending section and dipole vacuum chamber. The quadrupole triplet is mounted on top of the microtron

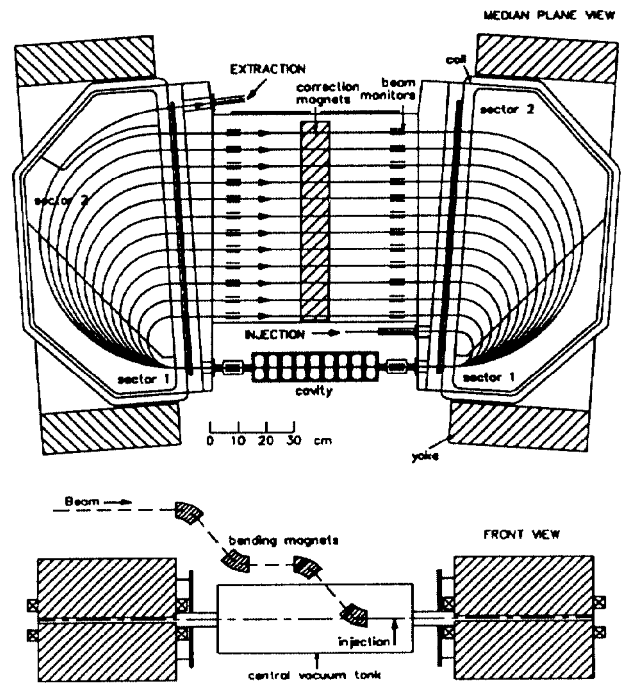

Figure 1: RTME with schematic lay-out of the injection line.

bending magnet, but its demontation will be far less complicated than the demontation of the bending section.

The beam transport line should provide adequate focusing, steering and positioning capability in order to match the linac beam to the acceptance of the microtron.

With a slit system the energy spread of the linac beam should be reduced to $|\Delta E/E| < 1\%$, being the energy acceptance of the microtron.

3 THE DOUBLY ACHROMATIC BENDING SYSTEM

A doubly achromatic ion optical system is a system that displays achromatic behaviour with respect to place as well as divergence of the particles.

Fig. 2 shows the proposed complete beam transport line with the doubly achromatic bending section. Four identical homogeneous bending magnets will be used with perpendicular entrance and exit of the transversing beam. The transverse phase space (x, x') refers to the bending plane of the system, the (y, y') plane to the motion per-

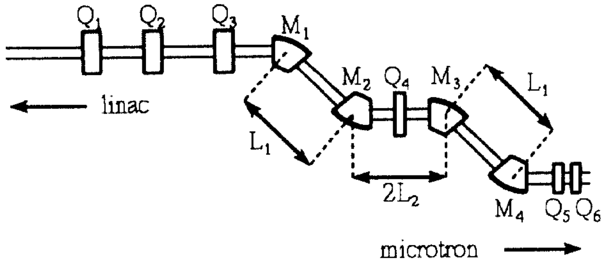

Figure 2: Lay-out of the injection line.

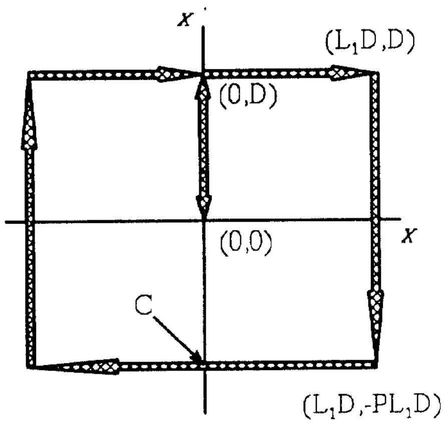

Figure 3: Motion in $x - x'$ phase space.

pendicular to the bending plane.

By decomposition of the radial transfer matrix of a bending magnet in the three elementary matrices the lens matrix and the positions of the pricipal planes are defined [3]. The distance l of the principal planes to the entrance, respectively exit of the magnet is given by $l = \rho \tan \phi/2$, where ρ is the radius of curvature and ϕ the bending angle. The lens matrix is given by

$$M = \begin{pmatrix} 1 & 0 & 0 \\ -P & 1 & D \\ 0 & 0 & 1 \end{pmatrix}, \tag{1}$$

with the focussing strenght $P = \sin \phi / \rho$ and the dispersion $D = \sin \phi$.

The condition for doubly achromatic transport can easily be given by considering the elementary motion in radial phase space for a particle with unit momentum deviation (see fig. 3 and table 1). Here the drift L_1 extends from the principle plane position of the first (third) bending magnet to the principal plane position of the second (fourth) bending magnet. The drift $2L_2$ is the distance between the principle planes of bending magnets 2 and 3.

The first bending magnet M_1 only has dispersive action and shifts the particle to $(x, x') = (0, D)$. The drift L_1 only changes the position of the particle and shifts the particle to $(x, x') = (L_1 D, D)$. The second bending magnet M_2 has both dispersive and lens action and places the particle at $(x, x') = (L_1 D, -PL_1 D)$. Note that the dispersions of the second and fourth bending magnet have negative values, since they bend over negative angles. The bending system is antisymmetric with respect to point C. Since the horizontal displacement in $x - x'$ phase space due to a drift over length L is given by Lx' it is seen that doubly achromatic behaviour takes place for $L_1 D = L_2(PL_1 D)$, or:

Table 1: Motion in $x - x'$ phase space

After element	(x, x')
M_1	$(0, D)$
L_1	$(L_1 D, D)$
M_2	$(L_1 D, -PL_1 D)$
L_2	$(L_1 D - 2L_2 PL_1 D, -PL_1 D)$
M_3	$(L_1 D - 2L_2 PL_1 D, PL_1 D)$
L_1	$(0, PL_1 D)$
M_4	$(0, 0)$

$$L_2 = \frac{\rho}{\sin \phi}. \tag{2}$$

This condition is independent of the distance L_1.

The drift lengths are the initial free parameters of the bending system. The length L_2 is fixed by the choice of magnet parameters (eq. 2). There is still freedom to put a demand on the particle transport for $\Delta p/p = 0$. For example one can require the system to provide parallel to parallel transport in the bending plane. This fixes L_1:

$$L_1 = 2L_2 = \frac{2\rho}{\sin \phi}. \tag{3}$$

Also interesting are the distances L_{b1} and $2L_{b2}$ between the bending magnets:

$$L_{b1} = 2L_{b2} = \frac{2\rho}{\tan \phi}. \tag{4}$$

By demanding the parallel to parallel transport the dimensions of the total doubly achromatic system are fixed. The bridged height H is given by

$$H = 4\rho. \tag{5}$$

The spanned length L is

$$L = \rho \left(\frac{4}{\sin \phi} + \frac{2}{\tan \phi} \right). \tag{6}$$

In this last equation L is taken from the beginning of the first bending magnet to the end of the last one.

The system described above does not offer any focusing in the y-direction. This can be accounted for, if necessary, by placing a quadrupole in the middle of the drift between the second and third bending magnet. In the phase space diagram this quadrupole is located at point C, $(x, x') = (0, -PL_1 D)$. At this position the quadrupole does not influence the doubly achromatic behaviour of the system since the focusing action of a quadrupole in first order only depends on the distance to the optical axis.

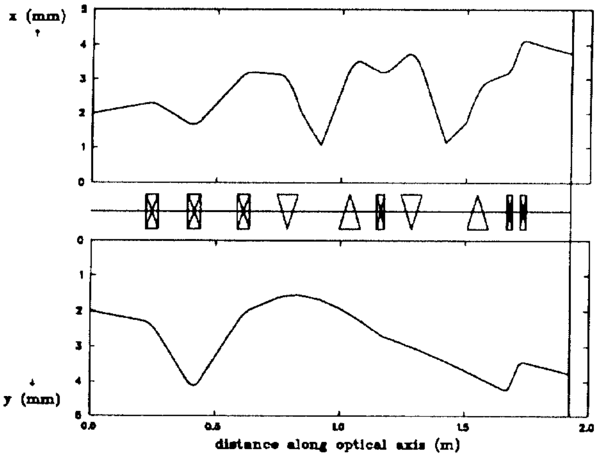

Figure 4: The beam envelopes along the proposed injection line

4 THE TOTAL BEAM TRANSPORT SYSTEM

With the constraints described in section 2 and the demand for a parallel to parallel transport the radius of curvature and bending angle of the bending magnets follow with equations 5 and 6: $\rho = 9.8$ cm and $\phi = 50$ deg. This implies (eq. 3) $L_1 = 2L_2 = 25.6$ cm and $L_{b1} = 2L_{b2} = 16.4$ cm (eq. 4). With these figures the field in the bending magnet must equal 3.574 kG, the effective field length is 8.6 cm, we choose a gap of 15 mm. The four identical magnets will be fed by one common power supply. For the proposed system small deviations in exitation current will not lead to variations in beam direction or spanned height.

With TURTLE the acceptance of the bending section is calculated. Then the starting quadrupole triplet with TRANSPORT is designed to match this acceptance. The quadrupole halfway M_2 and M_3 is adjusted to improve the beam parameters in the y-direction and finally the finishing quadrupole doublet is adjusted to match the beam to the acceptance of the microtron ($x, y \leq 4$ mm, $x' \leq 2.5$ mrad and $y' \leq 3$ mrad). For the design of the total beam transport line we took an estimate for the parameters of the linac beam envelope: $x = y = 2$ mm and $x' = y' = 5$ mrad. Once the emittance of the linac beam is measured we slightly have to adjust the parameters of the design. Figure 4 depicts the beam envelopes for the aforesaid choice of parameters. Table 2 depicts the parameters of the optical elements in the beam line.

Electron beam steering ($\pm$15 mrad) and positioning ($\pm$2.5 mm) in the x-direction is done with the last two bending magnets by putting small extra steering coils around the dipole yoke. Steering ($\pm$15 mrad) and positioning ($\pm$1 mm) in the y-direction is done by superponing dipole fields to the quadrupoles of the doublet.

Beam position monitoring with capacitive pick ups (resolution $\pm$0.2 mm) in both transversal directions will be done right after the linac and just in front of the entrance to the microtron in the dipole vacuum chamber.

Table 2: Parameters of quadrupoles and drift lengths

element	effective length (cm)	pole tip field (kG)	aperture radius (mm)
l_1	22.0		
Q_1	5.0	0.362	14.5
l_2	12.0		
Q_2	5.0	-0.589	14.5
l_3	15.0		
Q_3	5.0	0.313	14.5
l_4	11.0		
M_1	8.6	3.574	15 (gap)
L_{b1}	16.4		
M_2	8.6	3.574	15 (gap)
L_{b21}	16.4		
Q_4	3.0	-0.197	14.5
L_{b22}	16.4		
M_3	8.6	3.574	15 (gap)
L_{b1}	16.4		
M_4	8.6	3.574	15 (gap)
l_5	7.5		
Q_5	2.5	-0.728	10.5
l_6	2.5		
Q_6	2.5	0.776	10.5
l_7	18.4		

Since the linac is expected to deliver a beam with an energy spread of several percent (FWHM = $\pm$3%) and a low energy tail and since the energy acceptance of the microtron is limited to $|\Delta E/E| < 1\%$ it is advantageous to limit the energy spread in front of the microtron in order to minimize radiation production and activation (by a (γ,n)- reaction on the copper of the cavity). The energy selection will be done with a slit system in the focus of the first bending magnet. With the aforesaid beam parameters and quadrupole settings and a slit width of 0.13 mm a total beam reduction of about 80 % is calculated, while of the particles with $|\Delta E/E| < 1\%$ approximately 80 % is transmitted.

With this slit system in place pulse to pulse selection (the pulse length is 2μs and the repetition frequency is 50 Hz.) can be done with a laminated magnet placed between Q_2 and Q_3. A small deviation in the beam direction at this position will cause the beam to hit one of the slits.

5 REFERENCES

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