THE EXTRACTION ORBIT AND EXTRACTION BEAM TRANSPORT LINE FOR A 75 MeV RACETRACK MICROTRON

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A beam transport system providing dispersion matching of the beam from the cavity axis of a racetrack microtron to the injection position in an electron storage ring is described. For extraction the last bend in the 10 – 75 MeV racetrack microtron Eindhoven has been designed to be less than π rad. This is realised in a three sector dipole field for the last bend, as opposed to the normal two sector dipole field for the other orbits in the microtron. The combination of the last bend in the microtron and the first bending section in the beam transport line from the microtron to the 400 MeV storage ring EUTERPE forms a double achromat. The total transport line consists of two bending and two straight sections, with quadrupole doublets for transverse phase space matching between microtron and ring.

I. 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]. The final energy of 75 MeV is obtained by 13 subsequent passages through the accelerating cavity.

For extraction with a bending magnet, it is advantageous to increase the distance between the last and forelast orbit in the racetrack microtron. In section II is described how this is achieved by adjustment of the field profile of one of the microtron magnets. In section III is described how the extracted beam is dispersion matched to the transport line. The final bend towards the ring is provided by a 1.37 rad bending section with minus unity transfer matrix. The constraints for this transformation are derived in section IV. In section V the optical design of the total transport line is described.

The injection into the racetrack microtron is described in another paper in these proceedings [3]. In this paper the transverse phase space (x, x') refers to the bending plane of the system, the (y, y') plane to the motion perpendicular to the bending plane.

II. The last bend in the microtron

The bending magnets of the racetrack microtron consist of two distinct field levels for optimised focusing properties [2]. In order to obtain closed orbits (π rad bends) the magnets are rotated in their median planes over 78 mrad. It is favourable for extraction with a small dipole magnet, that the bending angle of the last orbit (75 MeV) is less than π rad, thereby increasing the orbit separation, which is 60.6 mm for the other orbits. This smaller bending angle can easily be achieved by altering the two sector

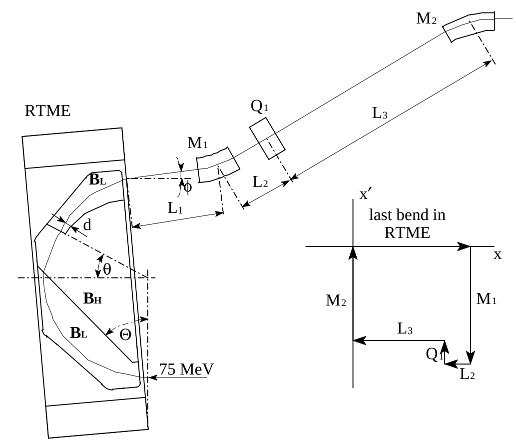

Figure. 1. The last bend in the racetrack microtron and the dispersion matching section.

profile into a three sector profile for the last bend only. The three sector profile consists of a low field section ($B_L = 0.51$ T), a high field section ($B_H = 0.60$ T) and again a low field section, see figure 1. In order to limit possible effects of the fringing fields due to the additional sector, the radial distance, d, between the forelast 70 MeV orbit and the sector edge is about 20 mm, where the gap is 20 mm in the low field section.

The sector angle Θ between the first low field sector and the high field sector is dictated by the electron optical design of the microtron. The adjustable parameter is the second sector angle θ. Decreasing θ yields an increased radial orbit shift and exit angle.

In a first order approximation in the magnetic fields the exit angle ϕ is given by [2]

$$\phi = (B_H/B_L - 1)\sin(2\Theta + \theta) \tag{1}$$

and the exit position y, with respect to the common drift on the cavity axis by

$$y = \frac{p/e}{B_L}\left[2 - (B_H/B_L - 1)\left[\cos(2\Theta + \theta) - \cos(2\Theta)\right]\right], \tag{2}$$

where p and e are the electron momentum and charge. The exit position is limited to approximately 945 mm by the extent of the vacuum chamber. With eqs. 1 and 2 this yields $\theta \simeq 0.52$ rad and $\phi \simeq 0.146$ rad and $y = 945$ mm.

The field map of the three sector magnet has been measured and with this map numerical orbit calculations have been performed. From the numerical calculations an exit position $y = 947$ mm and an exit angle $\phi = 0.10$ rad follow, close to the predicted values and sufficient for easy extraction.

Table I
The position after each element in (x, x') phase space throughout the last bend in the microtron and the first bending section for a particle with $\Delta p/p = 1\%$.

after element	position
last bend microtron	$(1, 0)$
drift L_1	$(1, 0)$
dipole M_1	$(1, -P_1 - D_1) = (1, D^*)$
drift L_2	$(1 + L_2 D^*, D^*) = (L_D, D^*)$
quadrupole Q_1	$(L_D, -Q_1 L_D + D^*)$
drift L_3	$(L_D + L_3(-Q_1 L_D + D^*),$ $-Q_1 L_D + D^*)$
dipole M_2	$(0, 0)$

III. Dispersion matching

Each individual complete orbit in the racetrack microtron forms a double achromat. The large dispersive action of the last bend will be accounted for by the first bending section in the transport line between microtron and the storage ring. This first bending section consists of two non-identical dipole magnets (M_1 and M_2) with the non-symmetrically placed quadrupole Q_1 in between. Since we have chosen to let the beam run parallel with the cavity axis after the first bending section the bending angle of the second dipole has to be 0.10 rad larger than the bending angle of the first dipole (see figure 1).

To a very good approximation the action of the last bend of the microtron can be regarded as the action by a π rad bend, which leaves a reference particle with a relative momentum deviation of unity ($dp/p = 1$) at position $(1, 0)$ in the (x, x') phase space. The drift L_1 to dipole M_1 does not influence the position in phase space. The first dipole shifts the reference particle both by dispersive and focusing action to $(1, -P_1 - D_1)$. Where $P_1 = \sin\phi_1/\rho$ is the focusing strength and $D_1 = \sin\phi_1$ the dispersive action of the decomposed bending magnet M_1. Here ρ and ϕ_1 are the bending radius and bending angle of the dipole, respectively. The subsequent actions by the drifts, the quadrupole, and the second dipole can be followed both in figure 1 and table 1. The drifts are taken between the subsequent principle planes.

The conditions for doubly achromatic behaviour of the combination of the last bend in the microtron and the first bending section are given by

$$L_3 = \frac{1 - L_2(P_1 + D_1)}{D_2} \tag{3}$$

and

$$Q_1 = \frac{-P_1 - D_1 + D_2}{1 - L_2(P_1 + D_1)}. \tag{4}$$

As can be deduced from eqs. 3 and 4 and the phase space figure, the quadrupole is focusing in the vertical plane. To avoid too strong focusing of Q_1, L_2 and/or ϕ_1 should be small. The minimum value for ϕ_1 is 0.44 rad and is fixed by the demand that the center of the transport line should pass at a minimum distance of 15 cm along the second bending magnet of the racetrack microtron. By this demand the bending angle of M_2 becomes 0.54 rad. The bending radius ρ is chosen 0.5 m.

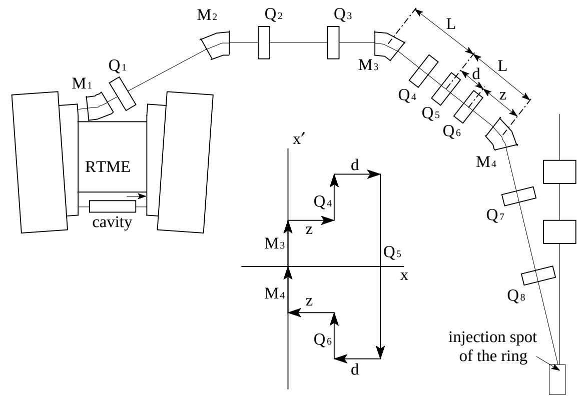

Figure. 2. The total transport line between the racetrack microtron and EUTERPE as well as the movement in horizontal phase space in the second bending section.

IV. The doubly achromatic bending system

The doubly achromatic bending section that bends the beam over 1.37 rad towards the injection spot of the ring consists of two identical bending magnets with a symmetrical quadrupole triplet in between, see figure 2. The last 0.20 rad bend into the ring is performed by a magnetic and an electrostatic septum.

For the design of this system the triplet at first is replaced by a single quadrupole, with focusing strength Q, preceded and followed by a drift L (= 0.43 m) to the dipoles. For $Q = 2/L$ this system is doubly achromatic. The total horizontal transfer matrix of this bending section is given by

$$M = \begin{pmatrix} -1 & 0 \\ \frac{2}{L} - 2P_{bend} & -1 \end{pmatrix}, \tag{5}$$

for $P_{bend} = 1/L$ this yields a minus unity transfer matrix.

The single quadrupole with the two drift lengths L and the decomposed horizontal plane transfer matrix

$$\begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -\frac{2}{L} & 1 \end{pmatrix} \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \tag{6}$$

is replaced by a quadrupole triplet with focusing strengths $-P$, Q_5, $-P$, drift lengths d between the quadrupoles and drift lengths z between the quadrupoles and the dipoles. By putting $P = 1/d$ and $Q_5 = 1/2L + 1/d$ the focusing strength of the triplet is equal to the strength of the single quadrupole [4]. The decomposed transfer matrix for the triplet in the horizontal plane is now given by

$$Triplet_{hor} = \begin{pmatrix} 1 & \frac{d}{2} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -\frac{2}{L} & 1 \end{pmatrix} \begin{pmatrix} 1 & \frac{d}{2} \\ 0 & 1 \end{pmatrix} \tag{7}$$

and the transfer matrix for the vertical plane by

$$Triplet_{ver} = \begin{pmatrix} 1 & -d(3 + \frac{d}{2L}) \\ 0 & 1 \end{pmatrix}. \tag{8}$$

This is the transfer matrix for a virtual negative drift. By demanding that the transfer matrix of the total bending section for the horizontal plane equals the minus unity matrix (eq. 5) the lengths of the drifts before and after the triplet are fixed by

$$z + \frac{d}{2} = L. \tag{9}$$

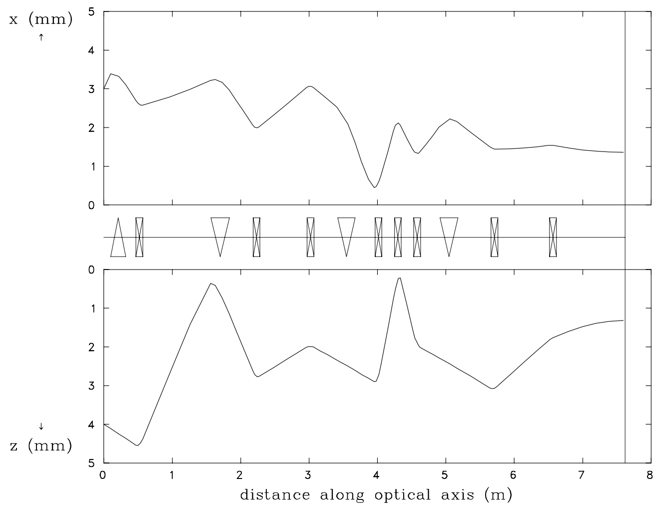

Figure. 3. The beam envelopes along the beam transport line.

In order to obtain the same minus unity matrix in the vertical plane for the total bending section, the following condition should be fulfilled

$$-3d - \frac{d^2}{2L} + 2z = 0, \tag{10}$$

where the two drift lengths z between triplet and dipoles are added to the drift in eq. 8. Eqs. 9 and 10 solve to $z = L(3 - \sqrt{5})$ and $d = 2L(\sqrt{5} - 2)$, which implies $Q_5 = \frac{1}{2L}(\sqrt{5} + 3)$ and $P = \frac{1}{2L}(\sqrt{5} + 2)$. Under these conditions the total doubly achromatic bending section yields a minus unity transfer matrix in both transverse phase spaces.

V. The total beam transport system

The two bending sections are connected via a straight section (of 1.58 m) with a quadrupole doublet, see figure 2. Also the last straight section (of 2.44 m) towards the injection spot of the ring is covered with a quadrupole doublet.

First the computer code TRANSPORT is used to establish the doubly achromatic behaviour of the two bending sections. Due to the difference in description, the lens strengths calculated in the previous section are slightly adjusted. Then the complete transport line is used as input and only the quadrupoles in the connecting doublets are allowed to vary. These doublets are adapted to match the transverse parameters of the beam from the microtron to the acceptance of the ring and to assure a beam waist in both transverse phase spaces at the injection spot of the ring.

The beam envelopes along the complete line are depicted in figure 3. As input beam the maximum emittance of the racetrack microtron is used (2 mm·mrad horizontal and 4 mm·mrad vertical) [2]. The two individually variable quadrupole doublets offer enough freedom to adjust the optics in case the emittance differs from the assumed one.

The field in the bending magnets is 0.50 T ($\rho = 0.50$m) and 0.66 T ($\rho = 0.38$m), respectively for the first and second bending section. The quadrupole gradient is maximal 12.4 T/m for an effective quadrupole length of 10 cm.

Beam steering in both directions will be done with steering magnets placed between the quadrupoles of the doublets and in the first bending section after the quadrupole. Beam position monitoring with capacitive pick ups will be done right after the microtron, just before injection into the ring and at several other places along the line. The ultra high vacuum system of the ring and the high vacuum system of the transport line will be separated by a thin foil ($\simeq 10\mu$m) which will only cause a minor emittance growth.

References

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