MATCHING THE EMITTANCE OF A LINAC TO THE ACCEPTANCE OF A RACETRACK MICROTRON

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A 10 MeV travelling wave linac will be used as injector for the 10 – 75 MeV racetrack microtron Eindhoven. The six dimensional emittance of the linac will be matched to the acceptance of the microtron. In longitudinal phase space the negative dispersive action of the first bend in the racetrack microtron is counteracted by the dispersive action of the doubly achromatic bending section in the transport line. The data for the longitudinal emittance are obtained from numerical simulations. The energy spread of the initial beam is larger than the energy acceptance of the racetrack microtron. It will be reduced with a slit system in a dispersive section of the transport line.

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] (see Fig. 1).

Section II gives a description of the linac and some measured and calculated data on the longitudinal behaviour of the linac. Section III describes the calculated acceptance of the racetrack microtron in the three phase spaces. In section IV the combination of the transport line and the first bend in the microtron which matches the linac beam to the acceptance of the microtron at the cavity is described. Section V presents some concluding remarks. The transverse phase space (z, z') refers to the bending plane of the transport line, the (x, x') plane to the motion perpendicular to this bending plane. The bending in the microtron takes place in the (x, x') plane. The longitudinal phase space is referred to as $(\Delta\phi, \Delta W)$. Since the coupling between the longitudinal and transverse phase spaces is only marginal in the transfer line, it is neglected.

II. The linear accelerator

The 10 MeV travelling wave linear accelerator is an 'old' medical linac (type M.E.L. SL75/10). At the Catherina hospital in Eindhoven it has been used for radiation therapy. The linac has been completely revised and is now suited for electron beam manipulation. Table 1 list some measured parameters of the linac.

The linac is controlled via PhyDAS (Physics Data Acquisition System), built around an MS68030 microprocessor and guarded by a programmable logic controller (PLC). The same PhyDAS system is also used as data-acquisition system for some experiments. The status of the accelerator, as monitored by the PLC, is displayed on the screen of a personal computer via the visualisation program Intouch.

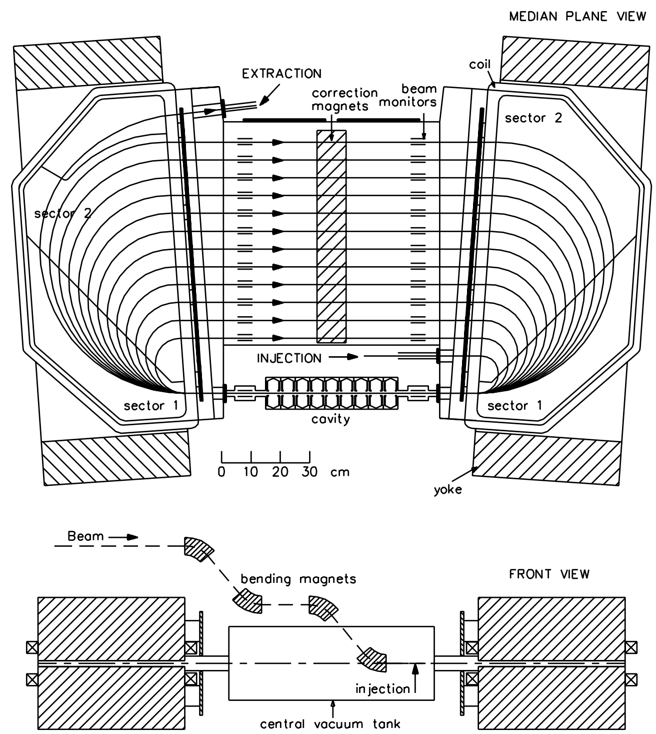

Figure. 1. RTME with schematic lay-out of the injection line.

The high power RF for the acceleration of the electrons is delivered by a 2.2 MW magnetron (EEV M5125). The accelerating structure of the microtron will be powered by the same type of magnetron. Synchronous operation of the two accelerators will be assured by injection locking of the magnetrons.

Fig. 2 depicts the measured and calculated energy spectrum of the linac. The spectrum is measured with a $\pi/6$-rad bending magnet. For the simulations the particle dynamics code Parmela has been used. The power and corresponding electric fields along the linac, used for this simulation, are calculated starting from the power diffusion equation with the numerical problem solver Matlab, where the geometry and Superfish results (shunt impedance, quality factor and Fourier coefficients for the electric fields) have been used as input. The calculated longitudinal phase space also is depicted in Fig. 2.

Table I
Parameters of the linac.

length (m)	2.25
electron energy (MeV)	10
FWHM energy spread (%)	3.5
macro pulse current (mA)	40
operating frequency (MHz)	2998.1
pulse repetition rate (Hz)	50, 150, 300
pulse duration (μs)	2.2
filling time (μs)	0.4

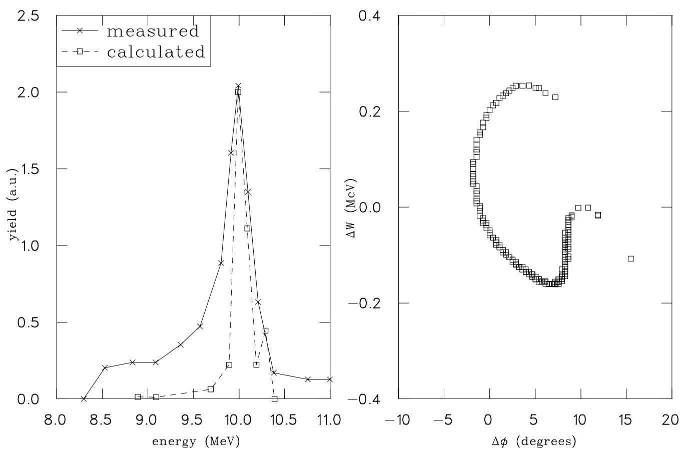

Figure. 2. The energy spectrum (left) and the longitudinal phase space (right) of the linac.

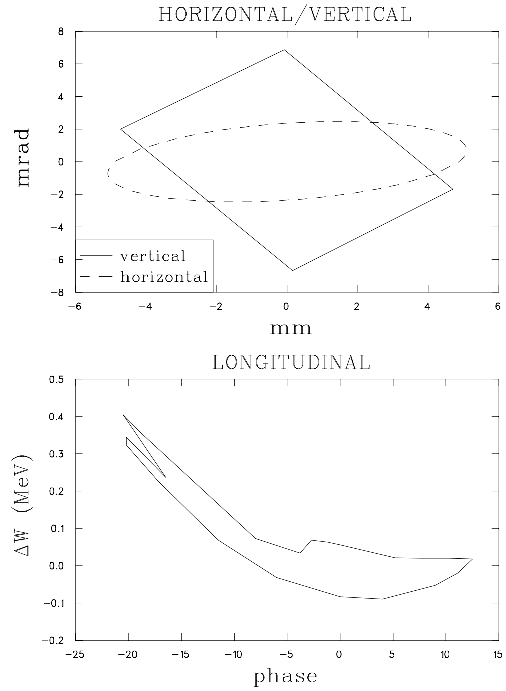

Figure. 3. Acceptance of RTME in the three phase spaces.

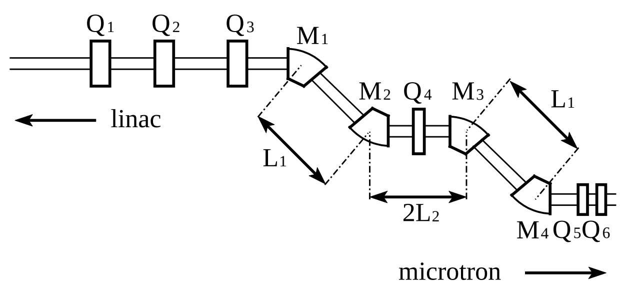

Figure. 4. Detailed lay-out of the injection line.

III. Acceptance of the microtron

The acceptances of the racetrack microtron have been obtained by numerical particle tracking. For this tracking procedure the measured field profiles of the two bending magnets has been used. The transverse focusing action of the cavity has been taken into account by using the transverse matrix for a standing wave accelerating structure as given by Rosenzweig [4].

The acceptances in the three phase planes are depicted in Fig. 3. The acceptances are calculated just before the first cavity passage, at the injection energy of approximately 9.96 MeV, where the cavity is assumed to be infinitely thin. The horizontal and vertical acceptances are 35 mm·mrad and 55 mm·mrad respectively. The longitudinal acceptance is 2.1 degree·MeV at a cavity accelerating potential V of 5.06 MeV and a synchronous phase ϕ_s of 9 degrees. The value for the longitudinal acceptance remains almost unchanged for $8 \leq \phi_s \leq 13$ degrees and $-1\% \leq \Delta V/V \leq 4\%$ [2].

Comparison between Fig. 2 and Fig. 3 shows that the microtron can not accept the complete beam from the linac in the longitudinal phase space.

IV. The transport from linac to cavity

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 and then brought down to the median plane of the microtron with a two step doubly achromatic bending system (Figs. 1 and 4).

Four identical homogeneous sector bending magnets will be used. Doubly achromatic behaviour takes place for [3]

$$L_2 = \frac{\rho}{\sin\phi}, \qquad (1)$$

where $2L_2$ is the distance between the principle planes of the second and third bending magnet, ρ is the radius of curvature and ϕ the bending angle. The condition is independent of the distance L_1 between the principle planes of the first (third) and second (fourth) dipole. For $L_1 = 2L_2$ this system provides parallel to parallel transport in the bending plane.

In longitudinal phase space $(\Delta W, \Delta\phi)$ the transfer matrix for the first bend in the microtron is given by

$$\begin{pmatrix} 1 & 2.58 \\ 0 & 1 \end{pmatrix}, \quad (2)$$

(2.58 mm/% or 9 degrees/%). Without counter measures the beam would be completely deformed and spread out in phase, thereby diminishing the number of electrons available for injection into the racetrack microtron. However the doubly achromatic bending section consisting of four dipoles has negative dispersive action. For dipoles with a bending radius $\rho = 9.8$cm at an angle $\phi = 0.873$ rad the transfer matrix of the beam transport in longitudinal phase space is given by

$$\begin{pmatrix} 1 & -2.03 \\ 0 & 1 \end{pmatrix}, \quad (3)$$

resulting in a total longitudinal transfer matrix for the transport between linac and cavity of

$$\begin{pmatrix} 1 & 0.55 \\ 0 & 1 \end{pmatrix}. \quad (4)$$

The positive dispersive action of the first bend in the microtron is thereby almost completely counteracted by the negative dispersive action of the bending section. And the match between acceptance and emittance is maximised.

Fig. 4 shows the beam transport line in some detail. The quadrupole in the middle of the drift between the second and third bending magnet offers some extra focusing in the x-direction. At this position it does not influence the doubly achromatic behaviour of the system.

A triplet matches the beam from the linac to the bending section. It also shapes the beam for effective energy selection by a slit that is placed in the focus of the first bending magnet. Here the energy spread of the beam is reduced. The linac delivers a beam with an FWHM energy spread of 3.5% and a low energy tail (Fig. 2), whereas the energy acceptance of the microtron is limited to $|\Delta E/E| < 0.8\%$ (Fig. 3). It is advantageous to limit the energy spread in front of the microtron in order to minimize radiation production and activation at higher energies in the microtron. At the slit a total beam reduction of about 80 % is calculated, while of the particles with $|\Delta E/E| < 0.8\%$ approximately 80 % is transmitted.

The doublet at the end of the transport line is used to match the beam in the transverse phase spaces to the acceptances of the microtron at the position of the cavity. The transfer matrix for the first bend in the racetrack microtron used in this calculation is obtained from numerical particle tracking through the measured field profile [2].

Fig. 5 depicts the transverse beam envelopes between linac and cavity, for starting values of $x_{max} = z_{max} = 2$ mm and $x'_{max} = z'_{max} = 4$ mrad. The final emittance at the cavity matches the acceptance in fig. 3. Also for different starting emittances this match can be obtained without any difficulties. Once the emittance of the linac beam is measured the final adjustment of focusing strength of the quadrupoles in the transport line can be made.

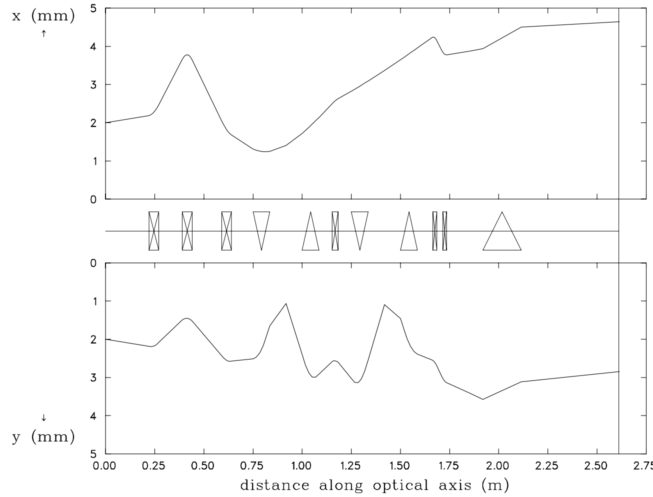

Figure. 5. Beam envelopes between the linac and cavity.

V. Concluding Remarks

A compact transport line that matches the six-dimensional emittance of a linac to the acceptance of a racetrack microtron is presented. The energy spread of the linac beam is reduced with a slit system in a dispersive section of the transport line. In transverse phase space the quadrupoles offer enough degrees of freedom to adjust the orientation of the emittance to the acceptance.

References

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