THE 75 MeV RACETRACK MICROTRON EINDHOVEN

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Abstract

The 10–75 MeV Racetrack Microtron Eindhoven (RTME) is designed to serve as injector for the electron storage ring EUTERPE. In RTME electrons are injected at 10 MeV by a travelling wave linac. The microtron's 5 MeV standing wave cavity, which is synchronized with the linac, accelerates the electrons 13 times. The main RTME magnets are two–sector magnets, which are tilted in their median planes, to provide strong focusing forces for optimal electron optical properties. Closed orbit conditions are fulfilled with the help of small correction dipoles located in the microton drift space; these dipoles are adjusted on the basis of beam position measurements. Isochronous acceleration is accomplished by position and phase measurements. An elaborate diagnostic system will be used for efficient commissioning of the combination of the 10 MeV linac and RTME.

Injector for EUTERPE

A 10–75 MeV racetrack microtron (RTME), which is shown in figure 1, has been chosen as injector for the 400 MeV electron storage ring EUTERPE [1], because a microtron offers a beam with small energy spread at low RF requirements. In RTME electrons are injected by a totally revised 10 MeV travelling wave linac (type M.E.L. SL75/10). The microtron's 5 MeV standing wave cavity, which is synchronized with the linac, accelerates the electrons in 13 times to their extraction energy of 75 MeV [2].

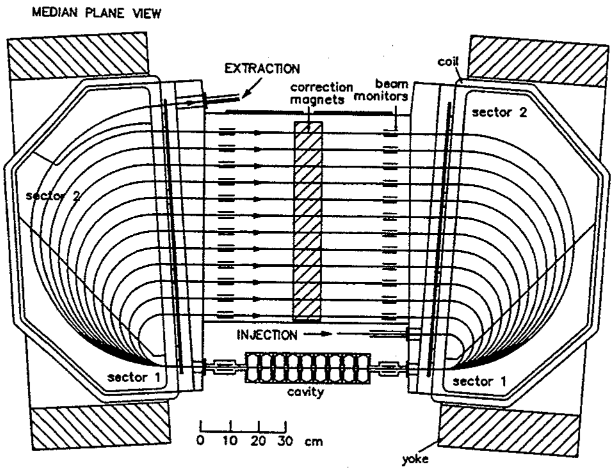

Figure 1: The 10–75 MeV Racetrack Microtron Eindhoven.

Basic Design

The design of the microtron is basically dictated by the two resonance conditions. First, the revolution time of the first orbit, t_1, is an integer multiple, μ, of the RF–period $1/f$ ($t_1 = \mu/f$). Second, each revolution time must exceed the preceding one by another multiple ($\Delta t = t_n - t_{n-1} = \nu/f$). From these resonance conditions two basic relations for a racetrack microtron are derived:

$$E_r = \left(\frac{\nu}{\mu - \nu - 2L/\lambda}\right) E_{inj}, \qquad (1)$$

and

$$B_r = \frac{2\pi f}{ec^2}\frac{E_r}{\nu}, \qquad (2)$$

where $\lambda = c/f$, E_{inj} is the injection energy, L is the field–free region between the magnets and B_r is the resonant or isochronous magnetic field, corresponding to the energy gain per turn, E_r. The maximum energy is given by $NE_r + E_{inj}$, with N the number of cavity passages.

The RF–frequency of the RTME cavity, f, must be the same as the RF–frequency of the 10 MeV linac. The mode number, ν, and the number of orbits, N, should be as small as possible to maximize the phase acceptance and to minimize phase errors due to imperfections of the construction [3]. The field–free region must be large enough to place the microtron's cavity. As we want to use normal conducting magnets, the magnetic field strength in the air gaps is limited by the maximum field strength in the iron (about 2 T for ordinary steel). The basic parameters that have been chosen for RTME are summarized in table 1.

Table 1: Basic microtron parameters.

Kinetic energy at injection [MeV]	10
Kinetic energy at extraction [MeV]	75
Energy gain per turn [MeV]	5
Number of orbits	13
RF–frequency [MHz]	2998
Resonant magnetic field [T]	0.524
Mode number μ	26
Mode number ν	2
Distance between magnets [m]	1

Two-Sector Bending Magnets

The main bending magnets of RTME have two magnetic field sectors to provide strong focusing forces. Sector 1 and 2 have magnetic field strengths of B_L and $B_H = aB_L (a > 1)$, respectively. The trajectories in the bending magnets consist of two circular arcs, defined by their centres M_1 and M_2, radii ρ and ρ/a

and angles 2Θ and $(\pi - 2\Theta)$, respectively (see figure 2). The tilt angle, τ, is retrieved from geometrical considerations:

$$\tan\tau = \frac{\sin 2\Theta}{\frac{a+1}{a-1} - \cos 2\Theta}. \qquad (3)$$

The magnetic field B_L is to be chosen:

$$B_L = \left\{ \frac{1}{a} + \frac{1}{\pi}\left(1 - \frac{1}{a}\right)(2\Theta + \sin 2\Theta) \right\} B_r, \qquad (4)$$

such that resonant acceleration is not violated.

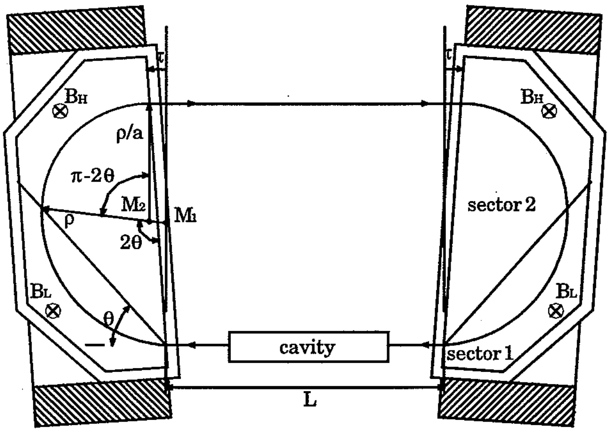

Figure 2: Two-sector magnets.

The parameters a and Θ, not prescribed so far, determine the focusing properties of RTME. Therefore, the transversal acceptance of RTME has been calculated for many combinations of a and Θ, where estimations for the fringing fields of the bending magnets with their field clamps have been taken into account [4]. Consequently, $a = 1.17$ and $\Theta = 45°$ have been chosen, which give a horizontal and vertical acceptance of 40 mm·mrad and 10 mm·mrad, respectively. With eq.(3) this yields $\tau = 4.48°$.

The racetrack microtron with two–sector bending magnets has been compared with a microtron with homogeneous magnets. For both types of microtrons the trajectories in the horizontal and vertical plane are plotted both for a parallel and a divergent beam at injection (see figure 3). The main difference is the periodicity of the betatron oscillations.

For the horizontal plane motion the tune of the two–sector option is 1.15 for the first and 1.07 for the final orbit. For the homogeneous option these numbers are 1.10 and 1.04, respectively. This leads to a smaller beam size in case of the two–sector magnets.

The stronger focusing would also lead to smaller vertical beam sizes if the defocusing of the fringing fields would be less. However, the fringing fields lead to a blow–up of the beam in the first turn (the trace of the matrix is larger than 2 [5]). The tune of the two–sector option is 0.22 for the second and 0.30 for the final orbit. For the homogeneous option these numbers are 0.09 and 0.05, respectively.

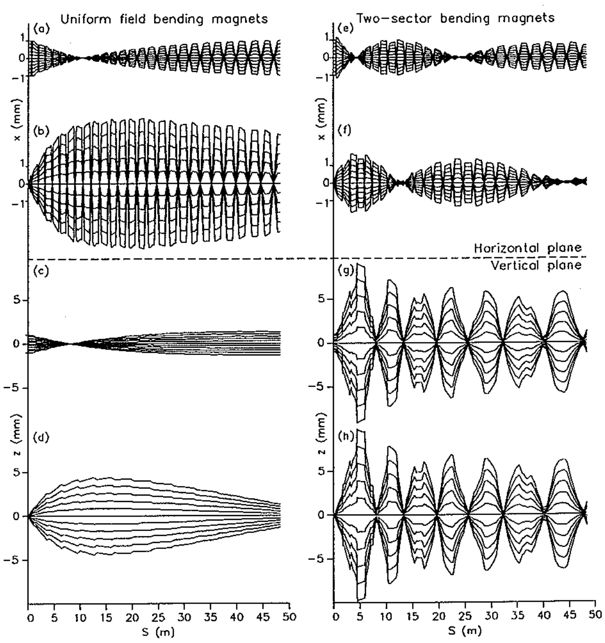

Figure 3: Trajectories in the horizontal and vertical plane for a parallel beam and for a divergent beam at injection. Homogeneous option: (a) x_0 = -1..+1 mm, $x'_0 = 0$, (b) $x_0 = 0$, x'_0 = -1.. +1 mrad, (c) z_0 = -1..+1 mm, $z'_0 = 0$, (d) $z_0 = 0$, z'_0 = -1.. +1 mrad. Two–sector option: (e) x_0 = -1..+1 mm, $x'_0 = 0$, (f) $x_0 = 0$, x'_0 = -1.. +1 mrad, (g) z_0 = -1..+1 mm, $z'_0 = 0$, (h) $z_0 = 0$, z'_0 = -1.. +1 mrad [2].

Misalignments and Magnetic Field Imperfections

Because of the strong focusing forces provided by the main bending magnets RTME operates further from integer resonances than conventional microtrons. Therefore the sensitivity for misalignments of the bending magnets is smaller. It has been investigated that all alignment tolerances can be met by mechanical alignment except for the tilt angle, τ.

Furthermore, the magnetic field maps of the main bending magnets have been measured. These field maps have been used for numerical orbit calculations, which have shown that it is not possible to obtain 180° bends for all orbits, simultaneously.

However, the effects of the alignment error of the tilt angle as well as the magnetic field imperfections can both be counteracted by an array of correction dipoles that is located in the field–free region halfway the two dipoles.

Diagnostics

An elaborate diagnostic system will be used for efficient commissioning of the combination of the 10 MeV linac and the 10 – 75 MeV racetrack microtron [6]. The commissioning will take place in two stages.

In the first stage the cavity will be replaced by a temporary beamline with a quadrupole and an OTR–set–up, which are used to measure the shape of transversal emittances [7]. Consequently, the emittance of the injected beam can be matched to the calculated acceptance of the microtron by adjusting the quadrupoles in the beam guiding system between the 10 MeV linac and RTME [8].

In the second stage the combination of the linac and RTME will further be assembled. Then the energy of the injected electrons, the cavity potential and the phase difference between the accelerating voltage of the linac and the cavity are adjusted. The energy of the beam is measured by means of the left RTME bending magnet, see figure 4. This is done for several different positions of the phase–shifter, which determines the phase difference of the accelerating voltage between the linac and the RTME cavity. Consequently, the energy will appear as a sine–like function of the position of the phase–shifter:

$$E = E_{inj} + E_{cav} \cos \phi, \qquad (5)$$

where E_{inj} is the energy of the injected beam, E_{cav} is the cavity potential and ϕ is the phase difference between linac and cavity. The mean of this function is the injection energy; the amplitude of the harmonic part is the cavity potential. Further, the measurement yields a calibration for the phase–shifter.

In the microtron many stripline beam position monitors (BPM's) are used to adjust the array of correction dipoles discussed in the previous section [9]. A phase–probe measures the phase difference between the cavity voltage and the first harmonic of the electron bunches in the field–free region of the microtron. This phase–probe can be placed in each of the twelve orbits. The phase–measurements as well as the beam position–measurements are used to optimize the adjustable microtron parameters.

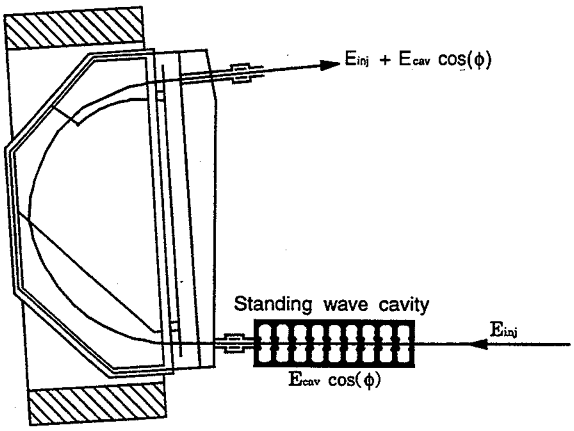

Figure 4: Left–hand RTME magnet used as spectrometer.

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