BEAM POSITIONING AND MONITORING IN THE RACETRACK MICROTRON EINDHOVEN

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A scheme to compensate for the effect of misalignments in the racetrack microtron Eindhoven is presented. An array of small dipole magnets will be employed to obtain closed orbits. These dipoles are located at the symmetry axis of the microtron, in the drift space between the two bending magnets. For each orbit a radial stripline beam position monitor (BPM) will be installed in the field free region. The strength of the corrector dipole magnet in the nth orbit is adjusted with the BPM signal in the $(n+1)^{th}$ orbit. The design of the BPM's is described. It will be shown that a rectangular geometry has a distinct advantage over a conventional circular geometry since it is less dependent on vertical displacements of the beam. Expressions for the difference-over-sum signal are given and compared with that for a circular geometry. Results of measurements performed in a test bench on prototype BPM's are discussed.

I. INTRODUCTION

The aims of the 400 MeV electron storage ring EUTERPE [1] are investigation of charged particle beam dynamics and application of synchrotron radiation. The EUTERPE injection chain consists of a 10 MeV travelling wave linac followed by the 10–75 MeV RaceTrack Microtron Eindhoven (RTME), see figure 1. Some design parameters of RTME are listed in table I. The whole system is currently under construction.

The main components of the electron optical system of the microtron are two 2-sector magnets separated by a drift space [2]. These magnets, which are tilted in their median planes to obtain 180 degrees bending angles, have been designed and constructed, and the magnetic field maps have been measured. Numerical orbit calculations show that it is not possible to obtain simultaneously 180 degrees bending in the horizontal plane for all the different energies. This is caused by the field 'dip', *i.e.* the smooth decrease of the magnetic field towards the centre of the magnets (about 2 % for RTME).

In Section II a scheme to correct for orbit deviations is pre-
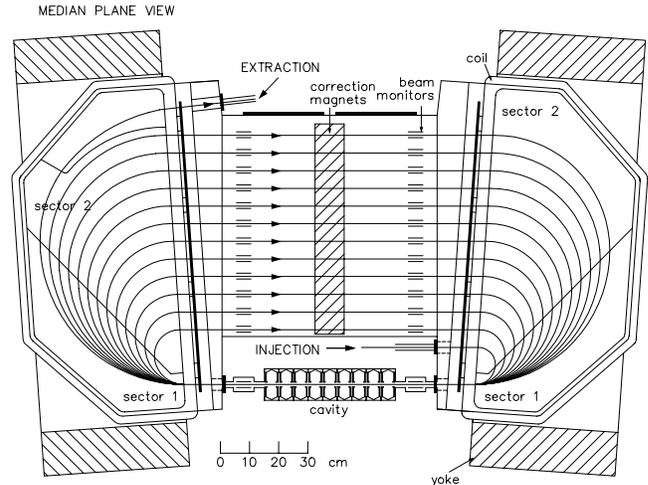
MEDIAN PLANE VIEW

Figure 1. RaceTrack Microtron Eindhoven.

Table I
Design parameters of the microtron.

Injection Energy [MeV]	10
Extraction Energy [MeV]	75
Energy gain per turn [MeV]	5
RF frequency [MHz]	2998
Low field sector [T]	0.51
High field sector [T]	0.60
Tilt angle [degrees]	4.0
Orbit separation [mm]	60.6
Drift length on cavity axis [m]	1.0

sented. Small dipole magnets will be used to provide an extra bending in the median plane. The signals of stripline BPM's are used to adjust the strength of these magnets. The design of these BPM's is described in Section III. Expressions for the difference-over-sum signal are given both for circular and rectangular geometries. It is shown that a rectangular geometry meets our requirements. In Section IV test bench measurements on prototype BPM's are discussed. Section V gives some concluding remarks.

II. CORRECTION SCHEME

The small deviations from the ideal bending angle of 180 degrees for the different orbits can partly be compensated for by an appropriate choice of the tilt angle of the main bending magnets (4.0 instead of 4.5 degrees). However for each orbit a small residual exit angle remains. Moreover an angular alignment tolerance for the tilt angle of 0.05 mrad would be required, which is far too stringent to be met by mechanical alignment. To compensate both for the residual exit angle as well as the mechanical angular alignment error of approximately 1 mrad an array of small dipole magnets is located halfway the two bending magnets. The magnetic field strengths of these correction magnets can be varied from -400 to 400 Gauss. This range is sufficient for the required bending angles, which are in the order of 10 mrad for the low energies and in the order of a few milliradians for the higher energies.

In RTME we have 14 degrees of freedom, *i.e.* the excitation of 2 bending magnets and 12 correction magnets, to fulfill the condition of closed orbits and the condition of isochronism. We determine these degrees of freedom using numerical orbit cal-

Figure 2. Proposed correction scheme.
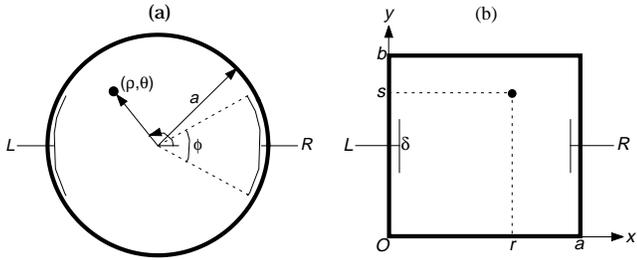
Figure 3. Beam position monitor with circular (a) and rectangular geometry (b).

culations. First we make estimations for the excitations of the main bending magnets. Then a backwards correction procedure is used to determine the excitation of the correction magnets, see figure 2. The beam position with respect to the ideal position in the $(n+1)^{th}$ orbit is used to adjust the magnetic field strength, $B_{c,n}$, of the correction magnet in the nth orbit. This procedure ensures closed orbits. However now the orbit circumferences are slightly changed. Therefore we must check on isochronism. If the condition of isochronism is not fulfilled as optimal as possible new estimations for the excitations of the main bending magnets have to be made, and so on.

This procedure is applicable if the errors in the measured beam positions are smaller than 1 mm.

III. DESIGN OF THE BPM

At the return path of each orbit a small piece of dummy beam pipe will be installed with two striplines facing each other. The striplines act as quarter wave transformers to the accelerating frequency. An extra array of BPM's is employed at the other end of the field free region to be able to measure the residual exit angles of the orbits. For the design of the BPM circular geometries as well as rectangular geometries are regarded, see figure 3.
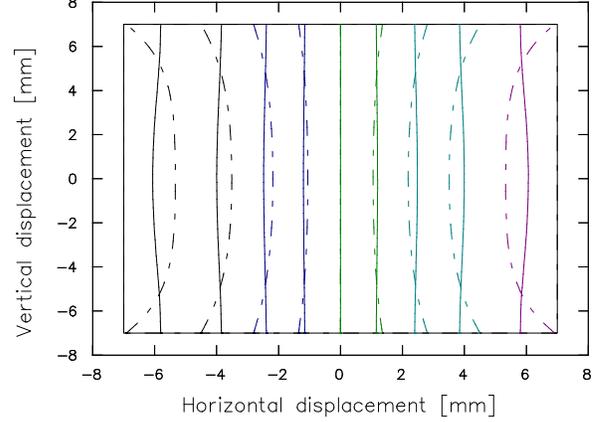
Figure 4. Contour plot of $\frac{R-L}{R+L}$ for the optimal circular (dashed lines) and rectangular geometry (continuous lines). The displacements are given with respect to the centre of the BPM.

The difference-over-sum of the left (L) and right (R) stripline signal only depends on the geometry of the BPM and on the beam position. For a circular geometry the difference-over-sum signal, derived with the two-dimensional Poisson equation, yields [3]:

$$\frac{R-L}{R+L} =$$

$$\frac{\sum_{n=1}^{\infty} \frac{1}{2n-1} \left(\frac{\rho}{a}\right)^{2n-1} \cos(2n-1)\theta \sin(n-\frac{1}{2})\phi}{\frac{\phi}{4} + \sum_{n=1}^{\infty} \frac{1}{2n} \left(\frac{\rho}{a}\right)^{2n} \cos(2n\theta) \sin(n\phi)}, \quad (1)$$

where (ρ, θ) represents the beam position in polar coordinates, a the beam pipe radius and ϕ the angular width of the striplines.

For a rectangular geometry the beam position is represented by (r, s), the beam pipe dimensions are $a \times b$ and the stripline width is δ. We derived the difference-over-sum signal analogously:

$$\frac{R-L}{R+L} = \frac{\sum_{n=1}^{\infty} A_n \left(\frac{\sinh\left(\frac{n\pi r}{b}\right)}{\sinh\left(\frac{n\pi}{b}(a-r)\right)} - 1\right)}{\sum_{n=1}^{\infty} A_n \left(\frac{\sinh\left(\frac{n\pi r}{b}\right)}{\sinh\left(\frac{n\pi}{b}(a-r)\right)} + 1\right)}, \quad (2)$$

where

$$A_n = \frac{\frac{2\sin\left(\frac{n\pi s}{b}\right)}{n\pi} \left(\cos\left(\frac{n\pi(b-\delta)}{2b}\right) - \cos\left(\frac{n\pi(b-\delta)}{2b}\right)\right)}{\frac{\sinh\left(\frac{n\pi r}{b}\right)}{\sinh\left(\frac{n\pi}{b}(a-r)\right)} \cosh\left(\frac{n\pi}{b}(a-r)\right) + \cosh\left(\frac{n\pi r}{b}\right)}.$$

Since the BPM signals are used for a correction in the horizontal plane we only want to measure horizontal displacements. Therefore we want the signal to be independent of vertical displacements, and linear with and sensitive to horizontal displacements.

For a certain geometry of the BPM these properties can conveniently be visualized by a contour plot [4]. Independency of vertical displacements is expressed by vertical contour lines,
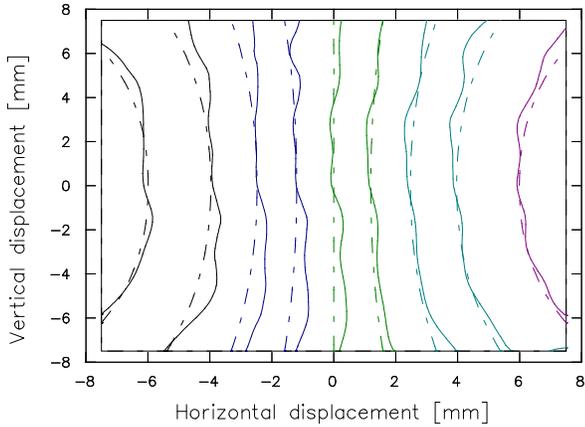
Figure 5. Comparison of measured (continuous lines) with calculated contour plot (dashed lines) for a circular geometry with $a^* = 11.5$ mm and $\phi = 0.70$ rad.

Figure 6. Comparison of measured (continous lines) with calculated contour plot (dashed lines) for a rectangular geometry.

linearity by equidistant contour lines and sensitivity by density of contour lines. The vertical independency can be influenced by the stripline width. Linearity and sensitivity depend on the dimensions of the beam pipe, which are tightly limited by available space and emittance of the electron beam. Hence in practice linearity and sensitivity can hardly be influenced.

The optimal circular BPM is found for $\phi \simeq 1$ rad. For a rectangular geometry the demand of vertical independency can be fulfilled much better, for $\delta \simeq \frac{3}{4}b$, see figure 4.

IV. TEST BENCH MEASUREMENTS

Measurements on prototype BPM's have been performed in a test bench, where the electron beam is represented by a 3 GHz signal on a 1 mm thick copper wire. The stripline signals are measured with calibrated crystal detectors.

A. Circular geometry

A BPM with a radius of 12.5 mm is considered. The striplines have a width of 8 mm, $\phi = 0.64$ rad. From the comparison between measured and calculated contour plot it can be seen that the measurements show a larger sensitivity. However in Eq.(1) the striplines are assumed to be part of the wall. Actually the striplines are both located 1 mm inwards. To compensate for this an *effective radius*, a^*, is introduced. The best match is found for $a^* = 11.5$ mm, see figure 5.

B. Rectangular geometry

For rectangular geometries an effective distance between the striplines (a^*) is introduced. A BPM with $a^* = 20$ mm and $b = 20$ mm, and 3 mm striplines is considered. The measured and calculated contour plot are shown in figure 6. The deviations in the corners of the figure are due to the fact that theory does not account for the finite thickness of the striplines ($\simeq 1$ mm).

V. CONCLUDING REMARKS

Numerical orbit calculations show that the proposed correction scheme is applicable to obtain closed orbits and isochronism in RTME at the same time.
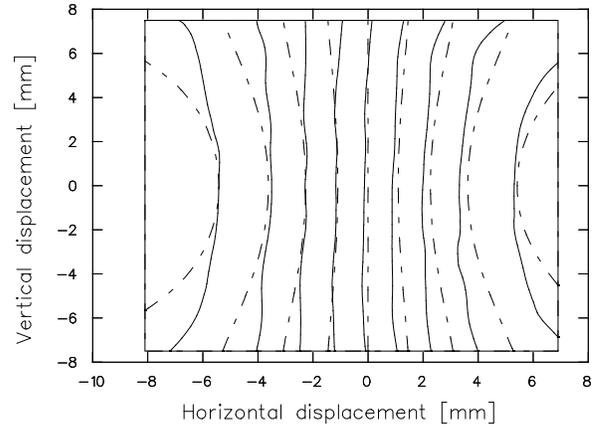
From the theoretical and experimental investigations it has been found that for our purpose the rectangular geometry is most appropriate since the demand of vertical independency is fulfilled as optimal as possible. For RTME 90 mm long rectangular BPM's ($a = 20$ mm, $b = 20$ mm and $\delta = 15$ mm) will be used to measure the horizontal displacements.

In the beam transport lines of the EUTERPE injection chain we will employ circular BPM's with the same radius as the beam transport lines. The angular width of the striplines will be 1 rad.

The accuracy in the measured beam position is mainly restricted by the measurement accuracy of the stripline signals. The definite detection electronics is still under development. Assuming that both the left and the right signal can be measured with an accuracy of 10 %, the horizontal beam position can be determined within 0.3 mm in the central region of the BPM. Other contributions, such as manufacturing errors and finite width of the electron beam, are estimated to be smaller than 0.3 mm in total.

References

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