A TUNING PROCEDURE FOR A RACETRACK MICROTRON

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Abstract

The electron-optical system of the Eindhoven RTM has been designed and constructed with non-stringent alignment and machining tolerances in the order of 0.1–1 mm and 0.1–1 mrad. The alignment and machining errors that are present can and must be counteracted with slightly different settings of the seventeen adjustable parameters (i.e. the excitation currents of the two end magnets and of twelve correction magnets (one at every turn), the beam energy and phase at injection, and the energy gain per turn), otherwise the beam will not be accelerated properly. All the errors are unknown and consequently their effects are unknown. Therefore, twenty-five beam-position monitors (BPMs) have been installed in the RTM (two for each turn and one at the extraction point) in order to measure the effects of the errors on the electron beam. The responses of the beam-positions at the BPMs with varying values of the RTM parameters have been studied. Based on these studies a tuning procedure is proposed and its usability and performance has been investigated with numerical simulations of the accelerator.

1 TUNING PROCEDURE

The approach for the Eindhoven racetrack microtron [1] is that all alignment and machining tolerances have been chosen such that these can be achieved without extraordinary measures (no difficult and expensive machining procedures and alignment procedures). The main bending magnets have been produced of ordinary steel with a constant gap for each sector, such that the field inhomogeneity is in the order of 1 % [2]. No expensive measures have been taken to decrease this inhomogeneity [3][4].

For the Eindhoven racetrack microtron it has been shown by Webers [2] that if the misalignments are within their (relatively large) tolerances there is always a solution for the adjustable machine parameters such that the isochronism deviations as well as the closed-orbit deviations are sufficiently small.

The seventeen adjustable parameters that can be used for tuning are listed in table 1. From the basic microtron equations [1] it can be seen that either E_{inj}, E_r, or B_r can be fixed, and the others should be adapted to it. For the Eindhoven racetrack microtron it has been chosen to fix the injection energy of the beam E_{inj}. Hence, sixteen adjustable parameters are left to counteract all the errors. Furthermore, twenty-five BPMs (two for each orbit and one at the extraction point) are used to find the optimal settings of the seventeen adjustable parameters.

Table 1 : The seventeen adjustable parameters of the Eindhoven racetrack microtron (the variable δB is defined as the half of the magnetic-field difference between the right and the left main bending magnet).

Adjustable parameter	Notation	Unit
Kinetic energy at injection	E_{inj}	MeV
Amplitude of the cavity potential	E_{cav}	MeV
Injection phase	ϕ	deg
Mean field of bending magnets	B	T
Field difference of bending magnets	δB	T
Excitation of n^{th} correction magnet	$B_{c,n}$	Gauss

The approach for the optimisation of the adjustable parameters is based on a brute-force method combined with a linear feed-back mechanism for the closed-orbit errors. Those parameters that influence the beam more than once, i.e. B, δB, E_{cav}, ϕ, will be tuned using a brute-force method, and those parameters that influence the beam once only, i.e. the correction magnets $B_{c,1}$ through $B_{c,12}$ will be tuned using a linear feed-back mechanism.

From figure 1, where B, δB, E_{cav}, and ϕ are varied over typical initial errors, it has been decided that B will be varied over 5 steps from –1 % to +1 %, δB over 3 steps from –1 % to +1 %, E_{cav} over 5 steps from –1 % to +1 %, and ϕ over 5 steps from –10 to +10 degrees. In total this gives $5 \times 3 \times 5 \times 5 = 375$ grid points in the four-dimensional B – δB –E_{cav} – ϕ space. At each grid point it is tried to guide the beam through the racetrack microtron by means of the twelve correction magnets.

For the tuning of the twelve correction magnets a linear feed-back mechanism is applied. For this purpose the beam-position monitors BPM_3, BPM_5, BPM_7, …, BPM_{25} are used. The responses of the correction dipoles on the beam positions at these twelve monitors have been determined by means of the numerical simulation

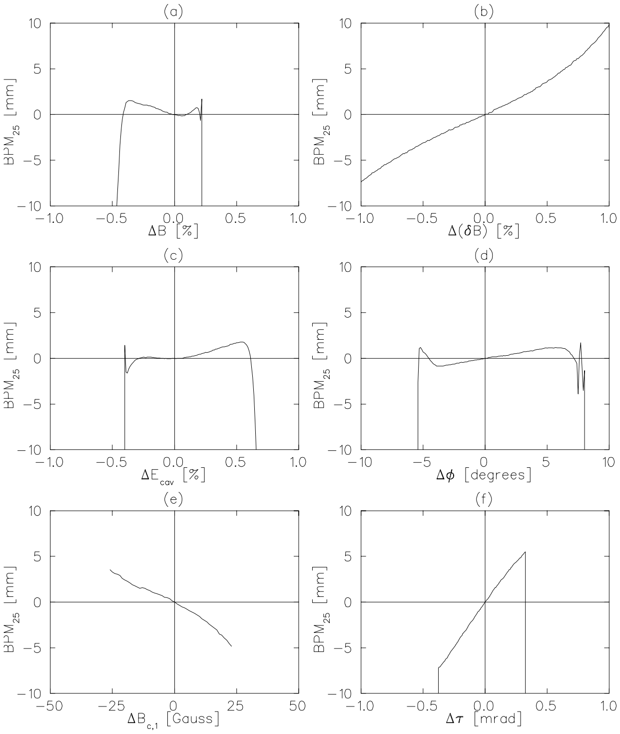

Figure 1 : The responses on the beam-position monitor at the extraction point of the Eindhoven racetrack microtron, BPM_{25}, as a function of variations in B (a), δB (b), E_{cav} (c), ϕ (d), $B_{c,1}$ (e), and the tilt angle τ (f), respectively.

program of the racetrack microtron, and these are used for the feedback control.

Most of the 375 grid points will not result in proper acceleration of the electron beam up to the extraction point. Consequently, in many cases the beam positions will be corrected well up to a certain orbit (this means that the beam-position deviations will be small up to a certain orbit), and in the next orbit the beam will not arrive at all. This is due to too high isochronism deviations. The control mechanism at this grid point has to be stopped.

2 TEST OF THE TUNING PROCEDURE

The tuning mechanism as described in the previous section has been tested using a numerical simulation program of the Eindhoven racetrack microtron. Many parameters of the racetrack microtron have been given all kinds of typical random Gaussian errors. The standard deviations of the microtron parameters are listed in table 2. Then the tuning mechanism has been applied. For each individual grid point in the four-dimensional $B - \delta B - E_{cav} - \phi$ space the maximum number of iterations has been set to 50. The result of one typical case is shown in figure 2. In this figure the last orbit where the beam is still measurable after the optimisation procedure of the

Table 2: The standard deviations for the microtron parameters as have been used for the test calculations.

Microtron Parameter	Standard deviation
Main magnetic fields	0.3 %
Cavity potential	0.3 %
Beam phase at injection	3.0 degrees
Kick of the correction magnets	0.3 mrad
Magnet positions	0.1 mm
Magnet angles	0.3 mrad

correction magnets is shown as a function of B, δB, E_{cav} and ϕ (these four parameters have been varied, with regular steps over the intervals shown in figure 1). There are two cases where the beam is extracted: ΔE_{cav}=1%, $\Delta\phi$=0 degrees, ΔB=0.5%, and $\Delta(\delta B)$=-1% or $\Delta(\delta B)$=0%. The estimated beam-current efficiency, i.e. the ratio of the extracted beam current and the injected beam current of the racetrack microtron, is 0.66 and 0.64, respectively. These are both acceptable. For the optimum the response on BPM_{25} has been calculated as a function of parameters B, δB, E_{cav} and ϕ (similar as in figure 1), and the results are shown in figure 3. The response plots are similar as those shown in figure 1.

This test has been applied many times for microtrons which all had different values for the alignment errors, machine errors, and initial parameter deviations. In all cases the problem has been solved. This means that there

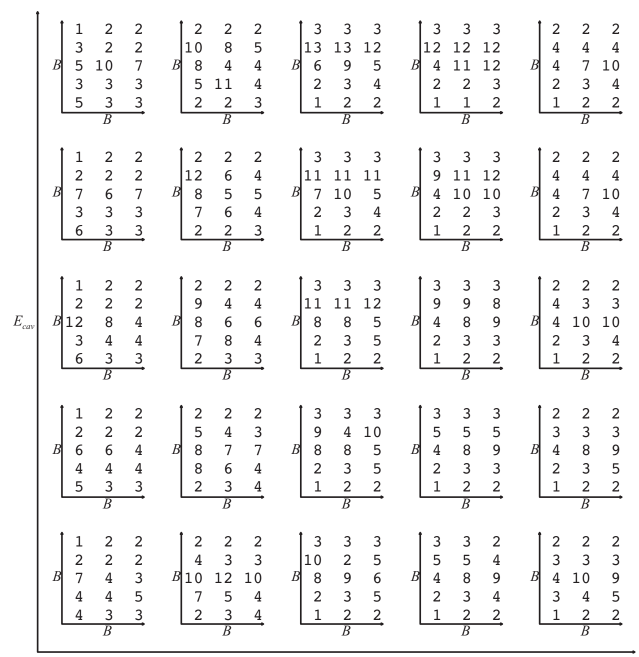

Figure 2 : The last orbit where the beam is still present after optimisation of the correction magnets as a function of B (-1.0, -0.5, 0.0, 0.5, 1.0 %), δB (-1.0, 0.0, 1.0 %), E_{cav} (-1.0, -0.5, 0.0, 0.5, 1.0 %) and ϕ (-10, -5, 0, 5 10 degrees).

has always been at least one grid point for which a solution has been found such that the beam reaches the extraction point with a reasonable amount of beam current. The mean number of total iteration steps appeared to be (2710 ± 90). The average of the total efficiency of the Eindhoven racetrack microtron, i.e. the percentage of the injected beam current that will be extracted eventually, appeared to be (68 ± 2)%.

Assume that about 3 seconds are needed between two iteration steps, mainly used for the re-adjustment of the correction magnets. In total, this means that about 2.3 hours are needed for the whole procedure, which is certainly acceptable. This time can be made shorter (if necessary) by making the tuning procedure more efficient in terms of the stopping criteria. In some cases it must be possible to terminate the control efforts for a certain grid point in an earlier stage. Furthermore, if the microtron has been operated several times, the starting values of the adjustable microtron parameters can be chosen better, and consequently the tuning procedure can become much quicker.

3 CONCLUDING REMARKS

The Eindhoven racetrack microtron has been designed without extremely-stringent requirements on machining and alignment. Therefore, a tuning mechanism has been designed which optimises the adjustable parameters that influence the electron beam in each orbit by means of a brute-force method. The adjustable parameters that influence the beam only once are optimised by means of a linear feed-back mechanism that uses the measured beam positions in the drift space. This method has been tested. An optimum has been found in all tested cases with an average efficiency of (68 ± 2)% and an average number of iteration steps of (2710 ± 90).

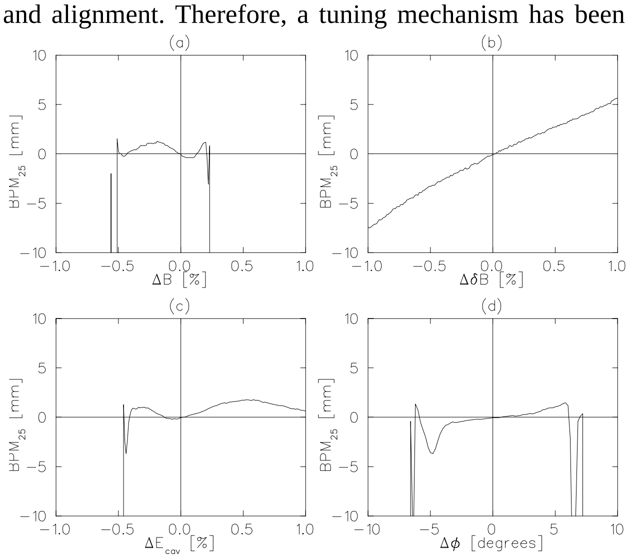

Figure 3: The responses on BPM25 as a function of variations in B (a), δB (b), E_{cav} (c), and ϕ (d), respectively. These calculations have been performed for the optimal setting as it has been found in the example.

4 REFERENCES

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