AN AUTOMATED TUNING MECHANISM FOR THE EINDHOVEN RACETRACK MICROTRON

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Abstract

An automated tuning mechanism for the adjustable parameters of the Eindhoven racetrack microtron is being developed. The microtron has seventeen adjustable parameters: the excitation currents of its two main bending magnets and of the twelve correction magnets (one at every turn), the beam energy and phase at injection, and the energy gain per turn. In order to meet both the closed-orbit condition as well as the isochronism condition, the adjustable parameters need to have specific values, which are affected by misalignments and machine errors much more than their tolerances. Hence, the adjustable-parameter values cannot be calculated sufficiently accurate beforehand as the misalignments and machine errors and consequently their effects are unknown. Twenty-five beam-position monitors have been installed in the microtron: two for each turn and one at the extraction point. A tuning strategy to find the optimized parameters settings from the beam-position measurements is proposed.

1 PROBLEM STATEMENT

Misalignments, machine errors and magnetic-field imperfections may have serious effects on the electron beam in a racetrack microtron, and can even cause complete loss of the electron beam. The effects of these errors can all be counteracted by slightly different settings of sixteen of the microtron's adjustable parameters, but the alignment and machine errors (and consequently their effects) are unknown. Consequently, the effects of all errors on the beam need to be measured in order to be able to calculate the required counteractions.

The tuning mechanism that is being developed will use the measured beam positions obtained during one trial to adjust the microtron parameters for the next trial. The adjustment will be based on a feedback control strategy that is being designed such that the tuning is completed in a minimal number of iterations. A brief description of the tuning mechanism that is under development is presented in this paper.

2 THE EINDHOVEN RACETRACK MICROTRON

A median plane view of the Eindhoven racetrack microtron is depicted in figure 1. From the isochronism condition two basic relations can be derived:

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

and

$$B_r = \frac{2\pi f}{ec^2} \frac{E_{cav}}{\nu} \tag{2}$$

where E_{inj} and E_{cav} are the injection energy and the energy gain per turn, respectively. B_r is the resonant magnetic field of the two main bending magnets, L is the distance between these magnets, f and λ are the RF frequency and the RF wavelength, respectively. The integer numbers μ and ν are the initial harmonic number and the incremental harmonic number, respectively. All parameters shown in equations (1) and (2) have been fixed mechanically in the design of the racetrack microtron except E_{inj}, E_{cav} and B_r, which have to be adjusted by the control system. In order to fulfil both equations (1) and (2), the value of one out of E_{inj}, E_{cav} and B_r can be fixed and the other two can be adapted to this value [1]. For the Eindhoven racetrack

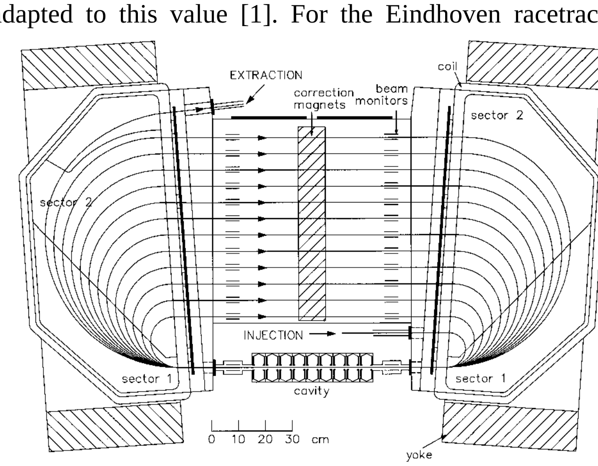

Figure 1: Median plane view of the Eindhoven racetrack microtron.

microtron it has been chosen to fix E_{inj} as this one is the most difficult to adjust. Furthermore the phase-difference of the injector linac and the microtron cavity, ϕ, which defines the phase of the injected beam with respect to the cavity voltage, can and should be tuned as the initial error is in the same order of magnitude as the width of the stable-phase area.

The main bending magnets of the Eindhoven racetrack microtron are two-sector magnets, which provide strong focusing forces [2]. The use of two-sector magnets makes it necessary to rotate the main bending magnets in their median planes over an angle τ, which is called the tilt angle. Because of the strong focusing forces the microtron operates sufficiently far from dangerous resonances. Consequently the microtron is very insensitive to errors, such as misalignments and machine errors. It has been shown that all alignment tolerances can be met by mechanical alignment, except for the tilt angle [2]. Therefore an array of correction dipoles has been installed in the racetrack microtron to compensate for the error in τ. Moreover the effects of the magnetic-field imperfections of the main bending magnets would also be disastrous, but these effects can also be counteracted by the correction dipoles.

In conclusion, all misalignments, machine errors and magnetic-field imperfections can in principal be counteracted with sixteen adjustable parameters of the racetrack microtron: the cavity potential E_{cav}, the phase difference between the injector linac and the cavity ϕ, the excitation currents of the two main bending magnets (these are defined as the mean magnetic field of both magnets, B_r, and the difference between the right and the left magnet, δB_r) and the twelve correction dipoles, $B_{c,1}$ through $B_{c,12}$.

As we explained, we approach the adjustment of parameters as a feedback control problem. In order to get a feeling for this control problem, the responses of all beam-position monitors have been calculated for each of the sixteen adjustable parameters that will be used for the tuning. The ranges of the adjustable-parameter variations have been chosen equal to the maximum expected initial error. As an example the response plots of some adjustable parameters at the left beam-position monitor of the sixth orbit are shown in figure 2. From these pictures it is clear that those parameters that influence the isochronism condition, i.e. E_{cav}, ϕ and B_r, show a limited stable area (which is smaller than the expected initial error). Within the area the beam passes the microtron, and outside the beam is lost after only a few orbits. The other parameters, i.e. δB_r and all correction magnets, of which the first is shown in figure 2, do not primarily affect the isochronism condition, but they lead to a slowly increasing deviation orbit by orbit. Hence, they do influence the closed-orbit condition.

In conclusion, the sixteen adjustable parameters can be gathered in two groups. The first group of three parameters influences the isochronism condition. The second group of thirteen parameters influences the closed-orbit condition: each orbit has a correction dipole to close that particular orbit, and δB_r can be used to restore the symmetry of the orbit pattern.

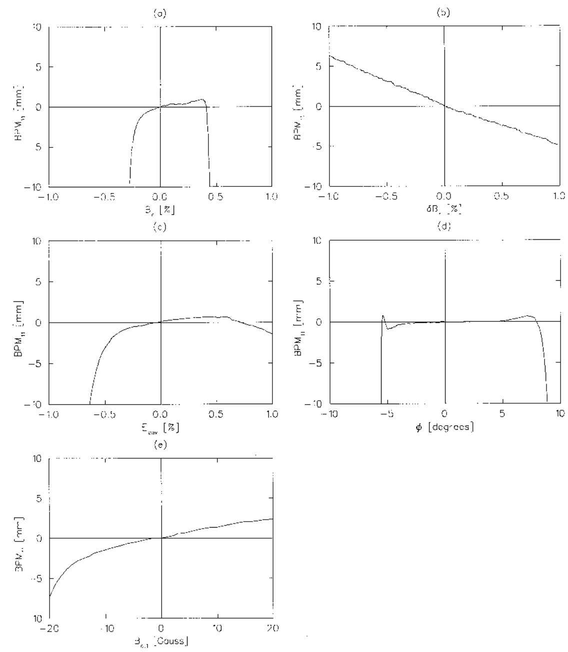

Figure 2: Response plots of (a) B_r, (b) δB_r, (c) E_{cav}, (d) ϕ, and (e) the first correction dipole. B_r and E_{cav} are given as a percentage with respect to their design values, the percentage δB_r is the relative increase of the right magnetic field and simultaneously the relative decrease of the left magnetic field with respect to the design value, ϕ and $B_{c,1}$ are given in absolute values.

3 BEAM MEASUREMENTS

In order to calculate the required counteractions the deviations from the closed-orbit condition and the isochronism condition have to be determined. This means that the beam-path lengths and the horizontal beam-position deviations (i.e. the beam-position deviations in the median plane) at the centre of the cavity of all twelve orbits have to be determined. However, it is almost impossible to measure beam-path lengths directly. Furthermore, the beam position inside the cavity cannot be measured for two reasons: it is impossible to install a monitor inside the cavity, and moreover all thirteen beams with energies ranging from 10 to 75 MeV are mixed inside the cavity. For the latter reason it is also impossible to measure just outside the cavity.

As direct measurements of the required beam properties are impossible, indirect measurements have to be performed. Therefore it has been decided to install twenty-five horizontal beam-position monitors at other locations in the microtron: two for each turn in the drift space where the 13 beams are separated, and one at the extraction point [3]. At these positions the beams with different energies are not mixed and there is sufficient space to install a monitor. There will also be two horizontal beam-position monitors at both sides of the cavity. These two will be used to determine the horizontal position and direction of the injected beam [4]. To perform this measurement the left bending magnet will be excited such that the electron beam will leave the microtron immediately after one cavity traversal, and consequently the thirteen beams do not mix inside the cavity. The complete orbit pattern inside the microtron will be estimated from the twenty-five beam-position measurements together with the information about the injected beam. From this orbit pattern the beam-path lengths and the beam-position deviations at the centre of the cavity will be retrieved.

4 TUNING MECHANISM

To estimate the beam-path lengths and horizontal beam-position deviations at the centre of the cavity using the beam-position measurements a simplified geometrical model of the racetrack microtron has been formulated, see figure 3. In this model the magnet edges are considered as hard edges and the magnetic field in each sector is considered as homogeneous. In the model several machine parameters that may have important errors, such as the tilt angle of both magnets, τ_L and τ_R, and the distance between the main bending magnets, L, are incorporated as fit parameters. This model is used to calculate the orbit pattern as a function of the injected beam and the fit parameters.

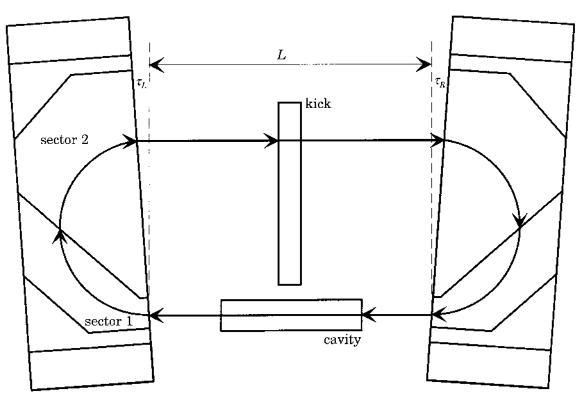

Figure 3: Simplified model of the racetrack microtron.

For the control strategy we consider using an iterative process. In one iteration of the tuning procedure, first some machine parameters of the model are fitted using the position information of the beam-position monitors together with the information about the injected beam. The thus fitted model is then used to estimate the path lengths and position deviations. This makes it possible to calculate new values for those parameters affecting the closed-orbit condition, i.e. the correction dipoles and δB_r. With these new settings for the correction dipoles and δB_r the path lengths can then be estimated more accurately, and it is possible to determine the deviations from the isochronism condition. Together with equations (1) and (2) new settings for those parameters affecting the isochronism condition, i.e. B_r, E_{cav} and ϕ, can also be determined. As the isochronism and closed-orbit condition are not independent completely, it will be necessary to check the closed-orbit condition again before a new iteration can be done. The thus computed settings for the adjustable parameters are applied to the machine and the next iteration can start.

This control strategy is currently under study. Based on numerical orbit calculations in which the magnetic-field errors are present and misalignments and machine errors can be incorporated, we will study the applicability of this control strategy. The most critical part of the proposed strategy will be the estimation of the deviations from the isochronism and closed-orbit condition by means of the beam-position measurements.

5 CONCLUDING REMARKS

All misalignments, machine errors and magnetic-field imperfections of the Eindhoven racetrack microtron can be counteracted with sixteen of the microtron's adjustable parameters: the energy gain per turn, the phase difference between the injector linac and the microtron cavity, the excitation currents of the two main bending magnets and the twelve correction dipoles. As the alignment and machine errors are unknown, their effects on the isochronism condition and the closed-orbit condition have to be measured in order to determine the required counteraction. However, these beam properties cannot be measured directly. Therefore other beam properties (the horizontal beam positions in the microtron drift space) will be measured. From these measurements the orbit pattern will be estimated and consequently the deviations from the isochronism and closed-orbit condition will be estimated. This information is to be used to determine the required counteractions.

The main strength of the proposed tuning strategy is the use of a simplified model of the machine, which only contains the most basic elements, together with a relatively large amount of beam-position monitors. Hence, it becomes possible to suppress the effects of measurement errors of the beam positions.

REFERENCES

[1] Theuws W.H.C., Botman J.I.M., Hagedoorn H.L., Proc. Part. Acc. Conf. Vancouver (1997).
[2] Webers G.A., Ph.D. thesis, Eindhoven University of Technology (1994).
[3] Theuws W.H.C., et al., Proc. Part. Acc. Conf., Dallas (1995) pp. 2738-2740.
[4] Theuws W.H.C., et al., Proc. Eur. Part. Acc. Conf. Barcelona (1996) pp. 1615-1617.