INJECTION OPTIMIZATION INTO AN RTM

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Abstract

The Eindhoven racetrack microtron (RTM) is injected from a 10 MeV linear accelerator on a first turn, to produce a 75 MeV electron beam after further acceleration. The matching of the linac emittance to the RTM acceptance is achieved in an iterative optimization procedure, which makes use of measurements of the beam shape in both transverse phase planes. The beam transport line from linac to RTM contains a double achromatic bending section and six quadrupoles for emittance matching. The beam shape is measured near the location of the accelerating cavity in the RTM. The designed feed-back procedure is described, and results of test calculations are given.

1 INTRODUCTION

Optimum transmission of the injector linac beam to the racetrack microtron (RTM) of the Eindhoven University [1,2] requires a feedback procedure for matching the measured linac emittance to the RTM acceptance. The transverse acceptance of the RTM has been determined by means of a numerical simulation program, which makes use of the measured magnetic-field maps of the main bending magnets and which uses a model for the transverse dynamics of the microtron cavity[3].

For the position where the measurements of the beam shapes in the transverse phase planes are performed Fig. 1 shows both the calculated acceptance of the RTM and approximated ellipses for the measured linac emittance, for ideal settings of the quadrupoles of the beam-transport line. One can see that the fit in the vertical plane is not optimal. Although small changes in the quadrupole settings would improve this fit, it would also make the fit in the horizontal direction worse simultaneously. Hence, the quadrupoles are set as a compromise between the horizontal and the vertical plane.

Alignment and machine errors, and errors in the emittance measurements may cause insufficient matching. The emittance measurements have to be fed back to the beam-line quadrupoles such that the measured beam shape will fit the calculated acceptance of the RTM. In this paper the design of the feedback procedure is presented.

The effects of errors can be counteracted by a slightly different choice of the beam-line quadrupole settings. Because the errors are unknown, their effects cannot be predicted and consequently the required settings for the beam-line quadrupoles cannot be calculated accurately enough beforehand. It is assumed that the Courant-Snyder parameters that describe the beam shape in the transverse phase planes can be measured within about 10 %. It has been chosen to use a fitting method to find the optimum setting for the beam-line quadrupoles. In this way the effects of the stochastic errors in the measurements are averaged out. In order to quantify the match of the measured and desired transverse beam shapes, an error function, σ, has been introduced, which expresses the match by a real value. This error function has been evaluated as a function of the beam-line quadrupole strengths, and a transfer-function model, describing the relation between quadrupole strengths and the error function, has been determined. The transfer-function model is based purely on polynomials that describe the effects.

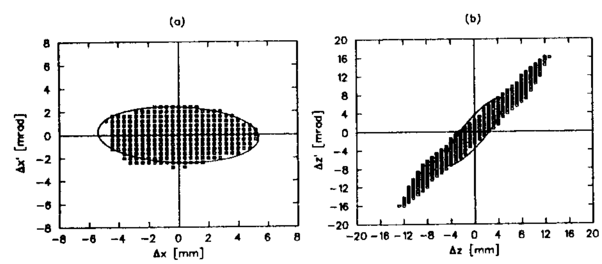

Figure1: Acceptances of the RTM, and approximated ellipses from linac emittance measurements.

2 FEEDBACK PROCEDURE

The principle of the feed-back procedure is that the error function will be evaluated experimentally for several slightly-different settings of the beam-line quadrupole strengths. The transfer-function model is fitted through these measured points, and accordingly the minimum value of the error function, together with the values for which this minimum is achieved, are calculated. Several iteration steps may be necessary to complete the optimization.

2.1 Error function

Results of measurements on the beam shape in the transverse phase planes are expressed in the Courant-Snyder (CS) parameters [4]. The feed-back mechanism must minimize the difference between the measured CS-parameters and the CS-parameters of the acceptance. The error function that has to be minimized has been chosen as:

$$\sigma = C_x^2((\beta_x - \overline{\beta}_x)^2 + (\gamma_x - \overline{\gamma}_x)^2) +$$
$$C_z^2((\beta_z - \overline{\beta}_z)^2 + (\gamma_z - \overline{\gamma}_z)^2),$$

where the CS-parameters with and without bars are for the emittance and acceptance figures respectively, and where C_x and C_z are factors that express the relative importance of the horizontal and vertical phase plane. From Fig. 1 it can be seen that the horizontal emittance has to be matched more precisely to the horizontal acceptance than the vertical emittance to the vertical acceptance. Hence, C_x and C_z have been chosen as the ratio of the emittance and the acceptance $\varepsilon_x / \overline{\varepsilon}_x$ and $\varepsilon_z / \overline{\varepsilon}_z$, respectively. The error function only contains 'β-terms' and 'γ-terms' as α, β and γ are connected by the relation $\beta\gamma - \alpha^2 = 1$. The projection of the phase-plane ellipse on the y- and y'-axis is equal to $\sqrt{\beta\varepsilon}$ and $\sqrt{\gamma\varepsilon}$. As matching along both axes is equally important the 'β-terms' and 'γ-terms' are weighted equally.

2.2 The transfer-function model

The number of tuning parameters in the transport line has been reduced to three: for a standard triplet configuration, with strength u_1, for one singlet with strength u_2 and for a standard doublet configuration with strength u_3.

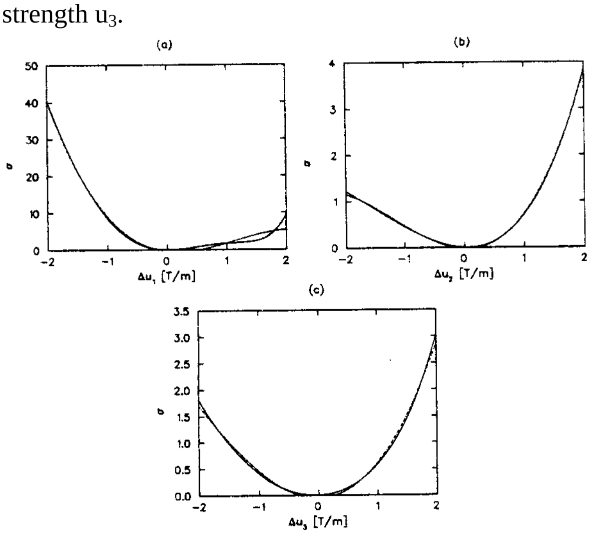

Figure 2: Error function for variations in u_1 through u_3. Dotted lines give third order polynomial fits.

The error function σ has been evaluated for variations of the tuning parameters, see Fig. 2. It can be seen that these functions can be described by third-order polynomials quite well. Also all cross terms up to the third order have been investigated and those which appeared to have a negligible influence on the error function have been left out in order to minimize the number of model parameters. Consequently, the transfer-function model becomes:

$\sigma = a_0 + a_1u_1 + a_2u_2 + a_3u_3 + a_4u_1^2 + a_5u_1u_2 + a_6u_1u_3 + a_7u_2^2 + a_8u_2u_3 + a_9u_3^2 + a_{10}u_1^2u_2 + a_{12}u_1u_2^2 + a_{13}u_2u_3^2 + a_{14}u_1u_2u_3$,

where the a_i (i = 0..14) are the fit coefficients. This model contains 15 coefficients, so more than 15 measurements have to be performed in order to be able to fit the coefficients a_i.

The error function can be interpreted as a beam loss percentage, as it deals directly with overlapping phase space areas. In our case a loss percentage of 5 % corresponds to σ = 0.5. This number has been chosen as the criterion value for proper matching.

3 TESTS OF THE OPTIMIZATION PROCEDURE

The optimization procedure has been tested numerically. At least 15 measurements have to be performed in order to be able to fit the error function. However, it has been chosen to perform 3 measurements for each knob, thus $u_i-\delta u$, u_i, $u_i+\delta u$ (δu = 2 T/m), and all combinations. This gives 27 measurements for each iteration step.

For a first test a random Gaussian error with a standard deviation of Δu has been added to all three tuning parameters u_1 through u_3. The average over 300 calculations with different errors of the needed number of iterations as a function of Δu is shown in Fig. 3.

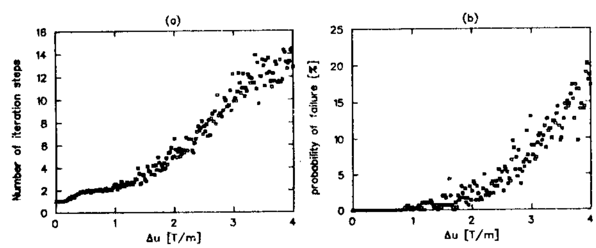

Figure 3: Average of needed number of iteration steps (a), and probability on a failing control (b).

If the optimisation procedure does not succeed in 100 iteration steps, then we say that the procedure fails. The probability that the control fails is shown as a function of Δu in Fig. 3 too. Errors in all quadrupole strengths up to about 2 to 3 T/m can be corrected with a reasonably small probability on failure 5 %. A maximum in the order of 5 to 10 iteration steps are needed. In practice, the maximum deviations are in the order of 0.5 T/m. Hence, the optimization procedure works without problems. For a successful simulation with Δu = 4 T/m the values of the CS-parameters are shown in Fig. 4 as a function of the iteration step.

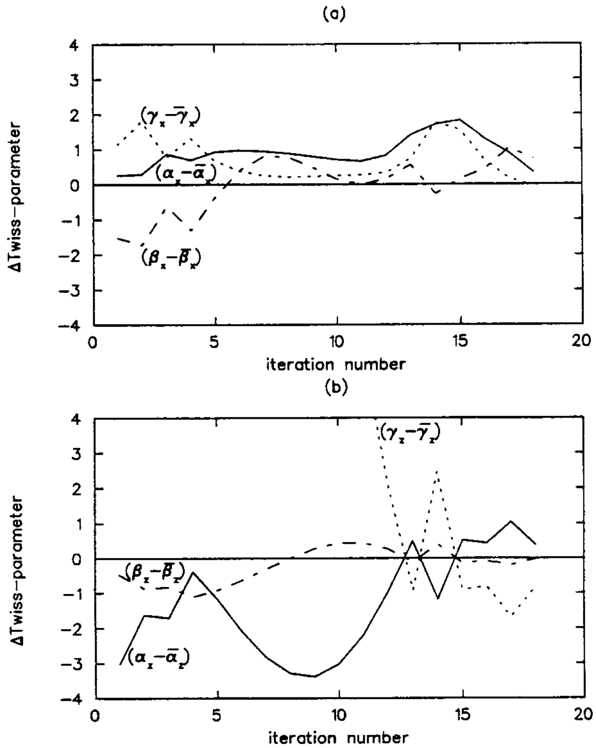

Figure 4: CS-parameters (β in [m], γ in [m^{-1}]) as a function of the iteration step.

A similar test has been performed for counteracting mechanical errors, e.g. drift length differences in the beam transport line, and tolerances on hardware structures. Also changes of the linac emittance through differences in settings of this machine have been considered, see Fig. 5. It is seen that beam shape errors up to 20% are corrected without problems.

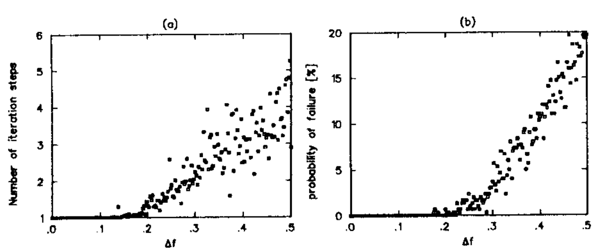

Figure 5: Average of needed number of iteration steps as a function of fraction Δf by which emittance β and γ have been varied, and probability on a failing control.

4 CONCLUSION

An optimization procedure has been presented for the injection beamline of the Eindhoven racetrack microtron. An error function criterion for the quality of the match between the measured and the desired transverse emittance has been defined, and a transfer-function model that describes this dependence has been derived. The proposed optimization procedure has been tested numerically. Quadrupole and length errors can be counteracted, as well as differences in transverse beam shape of the input beam as delivered by the linac of up to several tens of percent with a reasonably small probability on failure of the feed-back procedure.

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