DIAGNOSTIC SYSTEM OF THE EINDHOVEN LINAC–RACETRACK MICROTRON COMBINATION

W.H.C. Theuws, R.W. de Leeuw, L.W.A.M. Gossens, P.M. Spoek, J.I.M. Botman
C.J. Timmermans, H.L. Hagedoorn.
Eindhoven University of Technology, Cyclotron Laboratory,
P.O. Box 513, 5600MB Eindhoven, The Netherlands.

Abstract

An elaborate diagnostic system is presented for efficient commissioning of a 10 MeV linac and a 10–75 MeV racetrack microtron, which will serve as injectors for the electron storage ring EUTERPE. These injectors will be commissioned in two stages. First, proper injection of a 10 MeV electron beam into the microtron will be ensured. OTR, beam position and current measurements will be used to characterize the linac beam properties along the connecting beamline, such that the beam can be matched to the calculated acceptance of the microtron. Second, a 75 MeV electron beam will be extracted and optimized. Many beam position monitors will be used to fulfil the microtron's closed orbit conditions and to optimize certain critical parameters. One of the microtron magnets will be used as a spectrometer to determine the energy of the injected beam and the potential and phase of the accelerating cavity.

1 ACCELERATORS

A 10 MeV linac (LINAC10) and a 10–75 MeV racetrack microtron (RTME), connected by a doubly achromatic beamline, will serve as injectors for the 400 MeV electron storage ring EUTERPE [1]. This accelerator combination has 36 adjustable parameters in total: 8 parameters for LINAC10, 12 for the beamline, and 16 for RTME.

LINAC10 (see fig. 1) accelerates the electrons to an energy of 10 MeV. Its 8 adjustable parameters are: the gun filament current, three groups of solenoids, and four beam steerers. The gun filament current defines the energy distribution of the extracted electron beam. Three groups of solenoids focus the beam during acceleration. Two beam steerers for each of the two transversal directions centre the beam at extraction. The RF frequency is not an adjustable parameter; it is dictated by the structure of LINAC10.

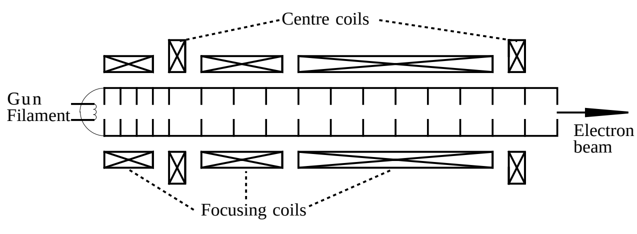

Figure 1: 10 MeV linear accelerator.

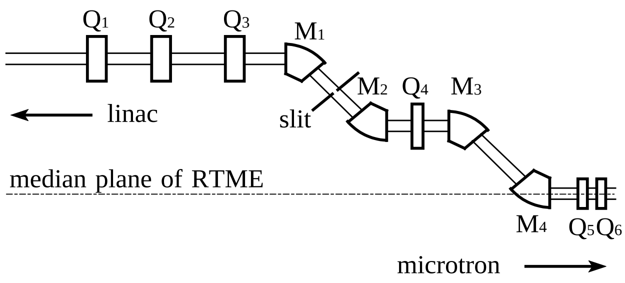

Figure 2: Beamline from LINAC10 to RTME.

The beamline (see fig. 2) guides the electron beam from LINAC10 to RTME [2]. Its 12 adjustable parameters are: one group of identical dipoles, six quadrupoles, four correction magnets and one slit. The dipoles, M_1–M_4, are excited by one single power–supply. The quadrupoles, Q_1–Q_6, are all excited independently. Dipoles M_3 and M_4 can be excited slightly differently from M_1 and M_2 to correct the beam position in the vertical plane. Quadrupoles Q_5

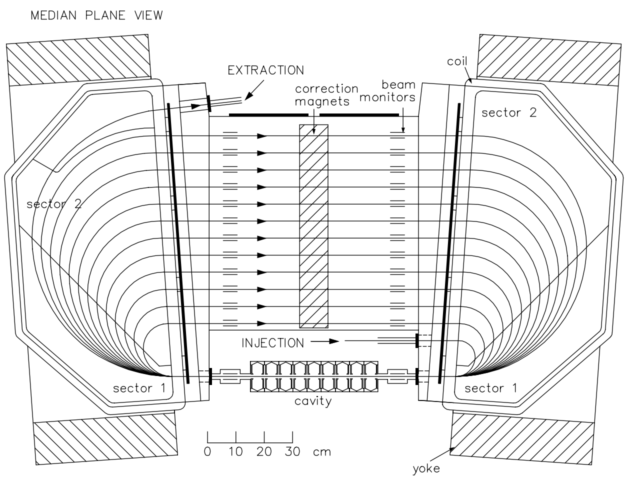

Figure 3: 10–75 MeV racetrack microtron.

and Q_6 have small dipole fields incorporated to correct the beam position in the median (horizontal) plane of RTME. The slit between M_1 and M_2 matches the LINAC10 energy spread to the RTME energy acceptance [2].

RTME (see fig. 3) accelerates the electrons from 10 to 75 MeV. Its 16 adjustable parameters are: two main bending magnets, twelve correction dipoles, the amplitude and the phase of the cavity potential. The main bending magnets provide recircular acceleration. Twelve correction dipoles (one for each orbit) ensure the microtron's closed orbit conditions [3]. The amplitude of the cavity potential and the phase–difference between the microtron cavity and LINAC10 are adjusted with an RF attenuator and a phase-shifter, respectively.

2 DIAGNOSTIC SYSTEM

Although settings can be calculated for all adjustable parameters described in the previous section, in practice these settings will not be ideal. This is caused by different kinds of errors, such as magnetic field imperfections and alignment errors. These errors cannot be incorporated in the calculations, but they can influence the beam dramatically. The effects of these errors must be counteracted with the adjustable parameters. Consequently, the calculated parameter settings must be tuned by using beam measurements.

The 3 groups of solenoids, two of the LINAC10 beam steerers and the beamline slit will be set to fixed values. The other 30 parameters will be tuned. More than 30 beam properties have to be measured throughout the microtron to tune these 30 parameters of the injectors. All beam properties are generally functions of all 30 free parameters, which leads to a very complex set of equations. The beam properties to measure have been chosen such that they depend on as little parameters as possible (preferably one); hence the complexity of the set of equations is broken down.

In two stages the commissioning of the accelerators will take place. In the first stage the RTME cavity will be replaced by a temporary beamline with a quadrupole, an OTR–setup and a current transformer. The matching of the transversal emittance of LINAC10 to the calculated acceptance of RTME with these diagnostics is described in section 3. In the second stage the accelerator combination will be built up completely. The adjustment of the most significant energy parameters is presented in section 4. The control of the beam position throughout the accelerators is handled in section 5. The optimization of certain basic parameters, such as the magnetic field strengths of the main RTME dipoles, is discussed in section 6.

3 TRANSVERSAL ACCEPTANCE

Certain diagnostic elements in a temporary beamline will be used to match the LINAC10 transversal emittance to the calculated acceptance of RTME. These diagnostic elements will be installed instead of the RTME cavity in the first stage of the commissioning.

A current transformer will be used to ensure that a maximal beam current is injected into the microtron.

An OTR–setup will be used to determine beam widths and divergences, which are measured as a function of the strength of a quadrupole that is placed some tens of centimetres upstream. Hence, the shape of the transversal emittance is determined [4].

Four Twiss–parameters are sufficient to describe the form of the calculated RTME acceptance for both transversal directions, denoted by x and z, *e.g.* $\bar{\alpha}_x$, $\bar{\beta}_x$, $\bar{\alpha}_z$ and $\bar{\beta}_z$. The equivalent Twiss–parameters of the beam emittance can be retrieved from the emittance measurement with the OTR–setup. From the differences between measured and the desired values of the parameters ($d\alpha_x = \alpha_x - \bar{\alpha}_x$, etc.) tunes for the beamline quadrupoles can be calculated from

$$dQ_i = \frac{\partial Q_i}{\partial \alpha_x} d\alpha_x + \frac{\partial Q_i}{\partial \beta_x} d\beta_x + \frac{\partial Q_i}{\partial \alpha_z} d\alpha_z + \frac{\partial Q_i}{\partial \beta_z} d\beta_z, \quad (1)$$

where $i = 1, .., 6$, denoting the beamline quadrupole. The partial derivatives are obtained from calculations.

4 ENERGY

The calculated optimal energies will be used as a first estimate when the commissioning of the accelerator combination is completed in the second stage. Three parameters related to energy are of importance for this purpose: the injection energy of RTME, the amplitude of the cavity potential, and the phase difference between LINAC10 and the RTME cavity. The injection energy is determined by the strength of M_1 and the beamline slit; the beam current passing the slit is optimized by varying the gun filament current. The cavity potential can be adjusted with an RF attenuator. The phase difference is set with an RF phase shifter.

The left–hand microtron magnet will be used to measure these three energy parameters. This magnet is excited such

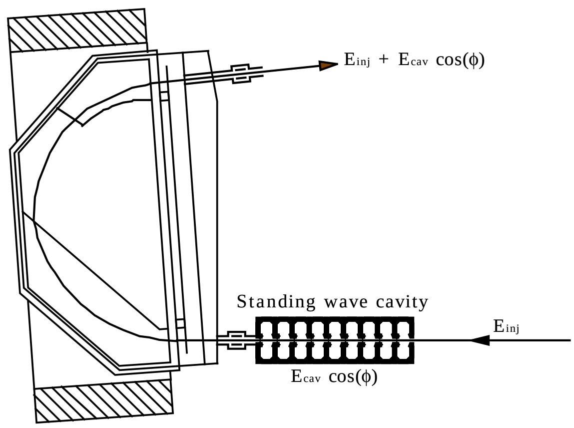

Figure 4: Left–hand RTME magnet used as spectrometer.

that the beam is extracted immediately after the first cavity passage without recirculating in RTME, see fig. 4. The excitation current of the magnet in combination with the BPM's just before and behind the magnet give the mean energy of the beam within a few promilles, relatively. This energy is measured for different settings of the phase shifter, which results in a sine–like form of the energy as a function of phase,

$$E = E_{inj} + E_{cav} \cos\phi. \qquad (2)$$

The injection energy, E_{inj}, is the mean of the function. The cavity potential, E_{cav}, is the amplitude of the harmonic part. At the same time the phase–difference, ϕ, is calibrated.

5 BEAM POSITIONS

Thirty–two stripline beam position monitors (BPM's) will be placed along the accelerators. Most of these BPM's will be used to tune the correction dipoles.

BPM's for both transversal directions will be used at many places. The BPM's directly behind LINAC10 are used to adjust the beam steerers of LINAC10 both in the horizontal and the vertical plane. Two BPM's for the horizontal and vertical transversal direction are placed just before and just behind the RTME cavity. The horizontal BPM's will be used to adjust the small dipole fields incorporated in Q_5 and Q_6. The vertical BPM's will be used to tune the excitation currents of M_3 and M_4. The BPM at the extraction point of RTME will measure both the horizontal and vertical beam position of the extracted beam.

BPM's that only measure the beam position in the horizontal plane are placed at 24 places in the microtron's drift space. Eleven of these 24 BPM's and the horizontal BPM at the extraction point of RTME will be used to control the 12 correction magnets in RTME [3].

6 OTHER CRITICAL PARAMETERS

Thirteen of the 24 BPM's will be used to optimize certain parameters: magnetic field strengths of the main RTME bending magnets, RTME injection energy, cavity potential and phase difference between LINAC10 and the RTME cavity.

Basis vectors are used to fit the beam positions in all thirteen BPM's by a least–square method. A basis vector is defined by the beam positions as a function of a unit deviation in one of the parameters. Basis vectors for all parameters mentioned above are retrieved from numerical calculations. The fit–parameters obtained from the least–square method are used to tune the parameters.

7 CONCLUDING REMARKS

The setting of most adjustable parameters can easily be retrieved from beam measurements. The complexity break down of the set of equations mentioned in section 2 can be carried through up to a very high degree, *e.g.* all correction dipoles can be adjusted with the measurement of one single BPM.

However, the beam properties must be reproducible as a function of the parameter settings, *e.g.* if the LINAC10 beam is unstable or not reproducible, it is impossible to set the RTME injection energy. The LINAC10 centre coils will be tuned on beam position just behind LINAC10. Consequently, a residual angle might be left. This angle is important in the definition of the energy by M_1 and the slit. Thus, if the angle is not reproducible, the RTME injection energy cannot be fixed.

The cavity energy gain is assumed to be established by the energy measurements. However, if the beam will be recirculating in RTME beam loading effects will influence this energy gain. A correction mechanism might be necessary.

Matching of the longitudinal emittance of LINAC10 to the RTME longitudinal acceptance cannot be done directly. In fact, the estimated energy parameters as defined in section 4 are results of numerical calculations. Starting with these values as a first estimate, the experiments with the diagnostics described in section 6 will point out if another choice of these values is necessary.

8 REFERENCES

[1] Botman J.I.M., Boling Xi, Timmermans C.J., Hagedoorn H.L., The EUTERPE facility, Rev. of Sci. Instr., vol. 63, no. 1 (1992) 1569–1571.

[2] de Leeuw R.W., Botman J.I.M., van Maanen I.F., Timmermans C.J., Webers G.A., Hagedoorn H.L., A 10 MeV injection beam transport line for a racetrack microtron, Proc. Eur. Part. Acc. Conf., London (1994) pp. 2417–2419.

[3] Theuws W.H.C., de Leeuw R.W., Webers G.A., Botman J.I.M., Timmermans C.J., Hagedoorn H.L., Beam positioning and monitoring in the racetrack microtron Eindhoven, Proc. Part. Acc. Conf., Dallas (1995) pp. 2738–2740.

[4] de Loos M.J., van der Geer S.B., Leemans W.P., Characterization of the 50 MeV ALS linac beam with optical transition radiation, Proc. Eur. Part. Acc. Conf., London (1994) pp. 1679–1681.