# High Precision Beam Energy Stabilisation of the Mainz Microtron MAMI*

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*Abstract*

To satisfy the demands of the parity violation experiment at MAMI, the energy of the 855 MeV c.w. electron beam delivered by three cascaded racetrack microtrons (RTM1-3) has to be stabilized to about $10^{-6}$. For this purpose a fast and a slow feedback loop has been installed. Provided that the longitudinal tune is well adjusted, the fast loop eliminates output energy deviations by acting on the RF-phase of RTM3. The slow loop stabilizes the online measured tune of this last stage by small changes of the RTM3 linac amplitude. To get the beam energy and the tune with the necessary accuracy, two features unique to an RTM are exploited, namely the large longitudinal dispersion of the $180°$ bending magnets and the large number of recirculations. In this paper the principal setup of the high precision beam energy stabilisation is shown and first results are presented.

## 1 INTRODUCTION

The Mainz Microtron MAMI [1] consists of three cascaded racetrack microtrons (RTM1-3) delivering an 855 MeV c.w. beam of both polarized and unpolarized electrons (cf. Fig. 1). Using normal conducting accelerating structures [2], the RTM3 linac for example provides an energy gain of 7.5 MeV, resulting in a total number of 90 recirculations. The RF-feedback [3] for one individual accelerating section is made up of three loops. The first one stabilizes the mean RF-amplitude, the second one locks the phase of the klystron output to the RF-master frequency and the third one tunes the resonance frequency of the whole section (cf. Fig. 2). Typical short term energy drifts of the 855 MeV beam are in the order of $10^{-5}$. But to determine the contribution of the strange quarks to the vector formfactor of the nucleon with the planned precision, the parity violation experiment [4] demands an energy stability of about $10^{-6}$. Taking advantage of the large longitudinal dispersion of the $180°$ bending magnets, a time-of-flight method [5] resolves output energy deviations with an accuracy of about 1 keV. The resolution is limited because fluctuations of the slope of the particles' trajectory contribute on the same level to the energy signal. The longitudinal tune of the RTMs is measured with the help of short and intense pulses superimposed on the c.w. beam (diagnostic pulse). A phase sensitive cavity on the linac axis then reveals the phase oscillation of the bunch centre (cf. Fig. 3).

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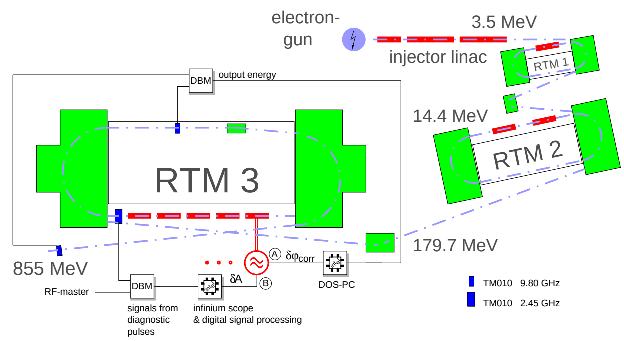


Figure 1: The Mainz Microtron cascade. Ⓐ: fast feedback loop. Ⓑ: slow feedback loop.

## 2 OPERATION PRINCIPLE

The injection into RTM3 guides the electron bunches parallel to the first recirculation path. A small phase and energy deviation $\vec{x}_0{}^T = (\delta\varphi(0), \delta E(0))$ from the reference particle in the midth of the recirculation region is assumed. Considering only linear terms and relativistic energies, the transformation [6] becomes

$$\vec{x}_n = M_n \vec{x}_0;\; M_n = \begin{pmatrix} \cos(n\Phi) & \beta\sin(n\Phi) \\ -\frac{1}{\beta}\sin(n\Phi) & \cos(n\Phi) \end{pmatrix} \quad (1)$$

for $n$ full recirculations. Typical values are 0.43 rad/MeV for the longitudinal $\beta-$function and $\Phi = 85°$ for the phase advance in RTM3 ($n \leq 90$). The tune is defined as $\Phi/2\pi$.

To compensate for errors $\delta E_{\rm err}$ of the output energy a fast feedback loop changes the input phase according to eq. 1 by an amount $\delta\varphi(0)$ such that

$$\delta E(90) = -\frac{1}{\beta}\sin(90\,\Phi)\,\delta\varphi(0) + \delta E_{err} = 0. \quad (2)$$

The necessary phase shifts $\delta\varphi(0)$ are realized by offsetting the phase of the RTM3 linac. To keep them as small as possible, we have choosen

$$\sin(90\,\Phi) = 1. \quad (3)$$

Hence the fast feedback is satisfied, if $\Phi = 85°$, because $90 \cdot 85° = 21 \cdot 360° + 90°$.

Given the amplitude $A$ of the linac, it's length $L$ and the energy $\Delta E$ the electrons gain, it follows from microtron theory [6], that

$$\cos\Phi = 1 - \pi\sqrt{\left(\frac{eLA}{\Delta E}\right)^2 - 1}. \quad (4)$$

The resonance condition of the microtron relates the magnetic field $B$ of the main dipols and the RF-wavelength $\lambda$ to the energy gain:

$$\Delta E = \frac{\lambda e c B}{2\pi}. \tag{5}$$

Calculating the total differential of the function $\Phi(A, B, \lambda)$ results in the following equation for RTM3:

$$\delta\Phi = -681.8° \cdot \left(\frac{\delta A}{A} - \frac{\delta B}{B} - \frac{\delta\lambda}{\lambda}\right). \tag{6}$$

The magnetic field $B$ and the wavelength $\lambda$ are stabilized to about $10^{-6}$ by means of a NMR probe and a quartz oscillator, respectively. The most volatile parameter is the linac amplitude which in the scale of minutes fluctuates in the order of $10^{-3}$. A $1.5 \cdot 10^{-3}$ change results in an unacceptable change of $90°$ of the phase function at the output of RTM3. Therefore, a slow feedback loop is needed to measure the tune of RTM3 and to apply a correction to the RTM3 linac amplitude to satisfy eq. 3.

## 3 IMPLEMENTATION

We have installed both loops as digital feedback loops due to the greater flexibility in improving the control algorithm. In a preliminary setup the fast loop consists of an interrupt driven DOS-PC which digitizes the energy signal and offsets the linac phase according to eq. 2. Technically this is achieved by simultaneously shifting the phases in the RF-circuits of all five klystrons (input Ⓐ in Fig. 2). Up to now we use the fast feedback at 100 Hz.

The slow feedback is realized with the help of diagnostic pulses. They are periodically injected into the cascade. The reference particle intentionally performs a phase oscillation of about $1°$ in RTM3 so that the tune can be measured at any time. The RTM3 linac amplitude is then corrected according to eq. 6. The digitalisation of the phase signals from the diagnostic pulses is done by an 8 GSa/s HP-infinium scope. Due to the large number of recirculations in RTM3 it is possible to measure $\Phi$ to about $\pm 0.3°$ which determines the product $90\,\Phi$ better than $\pm 27°$. The slow loop usually works at 0.2 Hz.

Both the DOS-PC and the scope are connected via Ethernet and GBIB to another PC which is integrated into the MAMI control system and provides the operator-interface of the energy stabilisation.

## 4 RESULTS

In a first test the fast loop digitized the energy at a rate of 1 kHz and averaged over 10 samples, applying a correction every 10 ms. As shown by the histograms in Fig. 4, both at $2.5\mu$A and $20\mu$A, which is the design current for the parity violation experiment, the stabilized output energy has a sigma-width of about $1.4$ keV.

In Fig. 5 the stabilized energy, the action of the fast loop and the online measured tune are shown under favourable

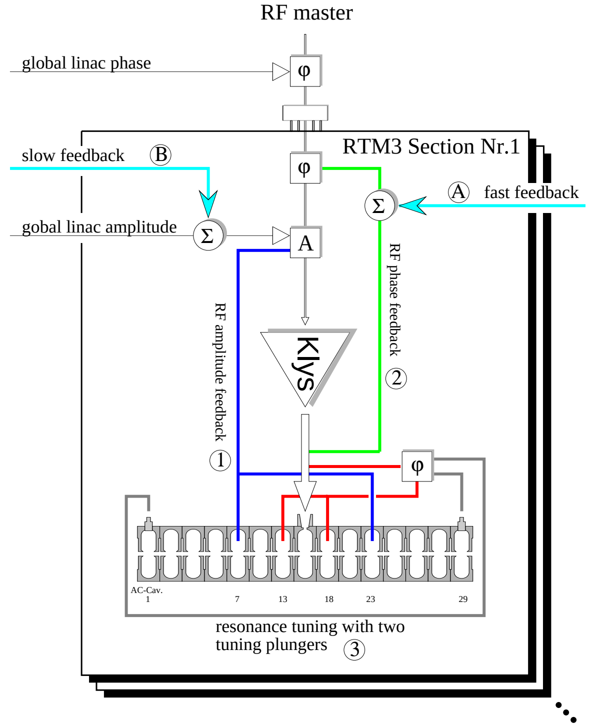


Figure 2: RF-feedback of RTM3. For clarity neither all 5 accelerating sections nor all 29 AC-cavities of a section are shown.

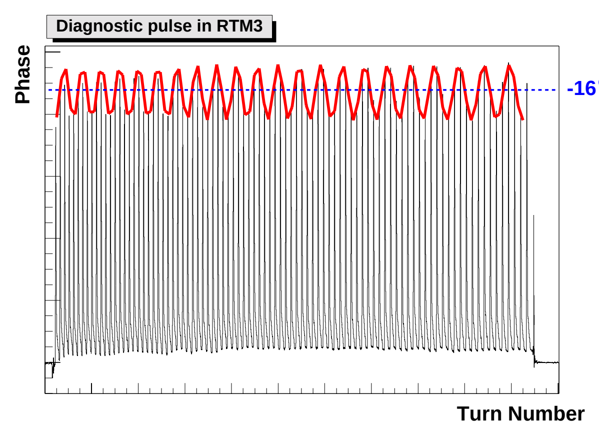


Figure 3: Phase oscillation in RTM3. The frequency of the amplitude modulation of the signals is proportional to the tune.

conditions, i.e. the tune is stable enough that no action of the slow loop was necessary. The dotted lines mark the region wherein $\sin(90\,\Phi)$ does not fall below $0.5$. Thus in this example the overall linac amplitude has been stable on the $1 \cdot 10^{-3}$ level for about one an hour. Since the presence of the diagnostic pulses has some disadvantages for the parity violation experiment, we made some extensive tests to find out how long one can do without the slow loop. It emerged that the adjusted tune is sometimes stable for several hours and sometimes does not last 5 minutes long. As

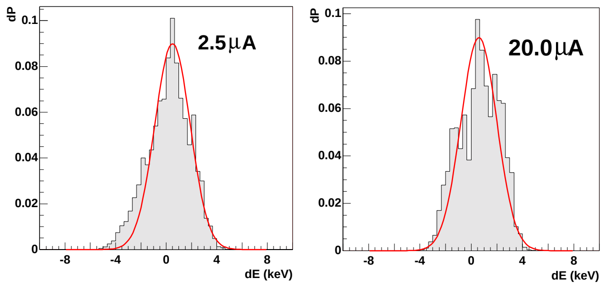


Figure 4: Histogram of the stabilized output energy sampled at 500 Hz over a period of 50 seconds.

pointed out in section 2 only a change of the linac amplitude can be responsible for this. On the one hand the RF amplitude feedback circuit (see ① in Fig. 2) itself is stable in the order of $10^{-4}$, which can't explain the observed behaviour. On the other hand we suspect that the movement of the tuning plungers changes the RF distribution in the linac sections in such a manner, that the field-probes no longer sense the mean value of the overall field.

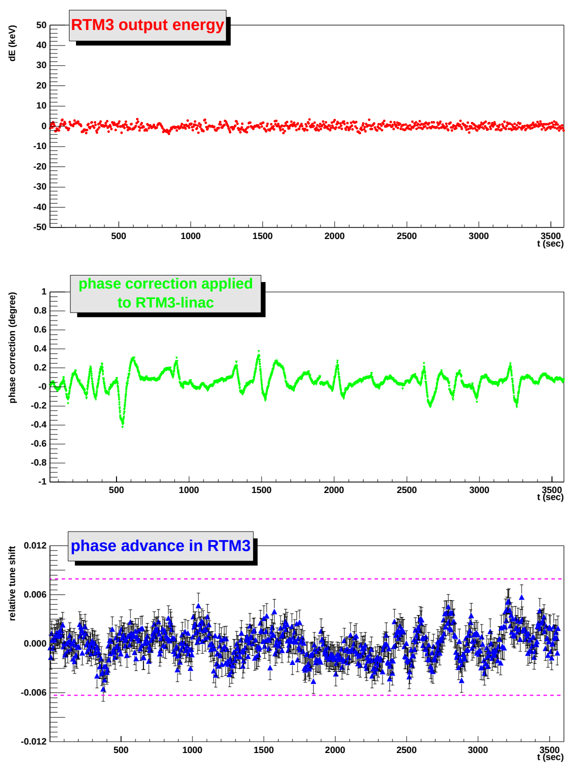


Figure 5: Both loops in action at 2.5$\mu$A under favourable conditions, i.e. the longitudinal tune does not demand any correction of the linac amplitude.

## 5 CONCLUSION

We have shown that it is possible to improve the short term energy stability by a factor of about 10 with the help of a fast feedback loop, provided that the longitudinal tune is well adjusted. The fast loop was tested up to a beam current of $20\,\mu$A, which fulfills the requirements of the parity violation experiment. The slow loop was successfully tested at 2.5 $\mu$A. A test at high currents will be conducted in the near future. Here, the enhanced noise level from intensity fluctuations of the c.w. beam makes it more difficult to extract the tune from the signals of the diagnostic pulses. A further objective will be to understand the reason for the sometimes larger than expected tune shifts. In order to check if a change of the RF-distribution in the accelerating sections is responsible, we will measure the temperature of the cooling water and the movement of the tuning plungers in correlation with the tune of RTM3. In case of clear and reproduceable correlations, the position of the tuning plungers will be used to calculate a correction value for the overall RTM3 linac amplitude. We hope that this will make it possible to omit the diagnostic pulses, which would be the prefered solution for the parity violation experiment.

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