BEAM MONITORS AT THE MAINZ MICROTRON*

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Introduction

The Mainz Microtron (MAMI) is a quite complicated cw-electron-accelerator consisting of three cascaded racetrack microtrons (RTM's) with a 3.5 MeV linac as injector [1, 2]. The demand for beam time by the nuclear physics experiments is overwhelming with often changing conditions for beam energy and intensity. Moreover, to supply a beam round the clock, MAMI must be run also by not too skilled operators. Therefore a reliable and redundant system to monitor the beam parameters at many points of the machine is necessary to have continually a clear idea of its condition and to allow for an extensive automatic beam steering and optimization by computer [3]. Tab. 1 gives an overview of the monitor devices we use versus the measured parameters.

Table 1: **Monitors at MAMI**

Para- ↓ meter	RF	FE	SR	SC	QU	TR	IC
i	x	x	x				
Δi		x					x
φ	x						
x/y	x			x	x	x	
$\emptyset$			x	x		x	
ε			x	x	x		

(RF - cavity, FE - ferrite, SR - synchrotron radiation, SC - scanner, QU - quadrupole (combined with another monitor), TR - transition radiation, IC - ionization chamber; to measure at the beam: i - current, Δi –losses, φ - phase, x/y - position, $\emptyset$ - profile, ε - emittance)

RF-Cavities

They determine the intensity, phase and center position of the bunched beam. Their design depends on the application: detection of the cw-beam or of the 12 nsec/100μA diagnostic beam pulses sent through MAMI during tune-up.

The cw-power out of a beam-excited resonator is given by [4]

$$P = i^2 \cdot r \frac{\kappa}{(1+\kappa)^2} \cdot B^2 \cdot \cos^2 \varphi, \text{where} \tan\varphi = 2\frac{Q_0(\nu_0 - \nu_R)}{1+\kappa}.$$

(i - beam current; κ - coupling factor $= Q_0/Q_L - 1$; ν_0, ν_R - bunch resp. resonator frequency; B - bunching parameter ≈ 1; r - shunt impedance: r = const. for a TM_{010}-intensity/phase-monitor and r = const.$\cdot(x/\lambda)^2$ for a TM_{110}-position-cavity).

Small detunings of a cavity (mainly by its temperature) are unavoidable, therefore one has to make a compromise between signal level ($\kappa = 1$, critical coupling) and a good signal stability (small φ, i.e. $\kappa \gg 1$). For our precision intensity-monitors measuring the beam current down to some nA to better than a few percent we take $\kappa = 3$; the signal is reduced by only 25%, but the frequency sensitivity to 1/4. For the cw-phase monitors to measure small energy changes of the beam by its time of flight (e.g. in the injector linac at $\leq$2 MeV and in the dispersive parts of the magnet systems between the RTM's) a high precision of $< 0.5°$ is necessary; therefore they have a low loaded quality factor Q_L (κ = 15–18). Moreover an autodyne method is used here: both the cavity and the reference signal are mixed down to 100 kHz and they gate the counts from a 50 MHz-oscillator.

The signal power out of a TM_{110}-position-monitor is much smaller than that from a TM_{010}-cavity, because the beam is crossing it near a field-node ($x \ll \lambda$); i.e. a maximum sensitivity is required: $\kappa = 1$ and a large shunt impedance r. The mode stabilizers in our position-cavities are built as capacitive cylinders (Fig. 1), drawing the electric field maxima inwards from $x = 0.481R$ for a pure TM_{110}-mode. By the steeper gradient of the electric field r can be increased by up to a factor of five [5].

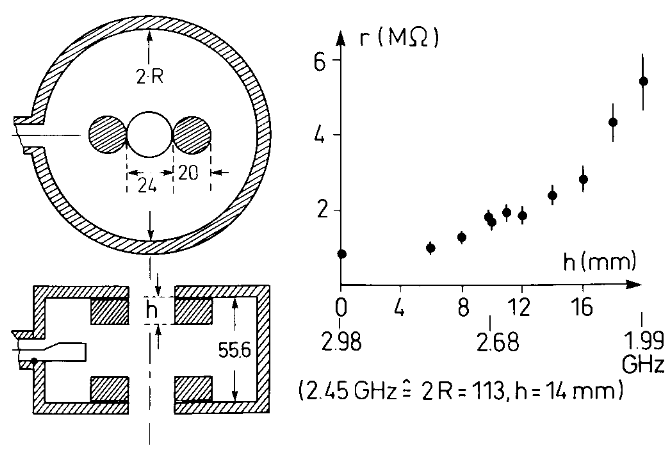

Figure 1: "TM_{110}"-position-monitor with capacitive cylinders for increase of r and mode stabilization

For the tagged-photon facility of MAMI a position monitor was demanded to detect beam deviations of 0.05 mm at currents of 1 nA, corresponding to a cavity power around

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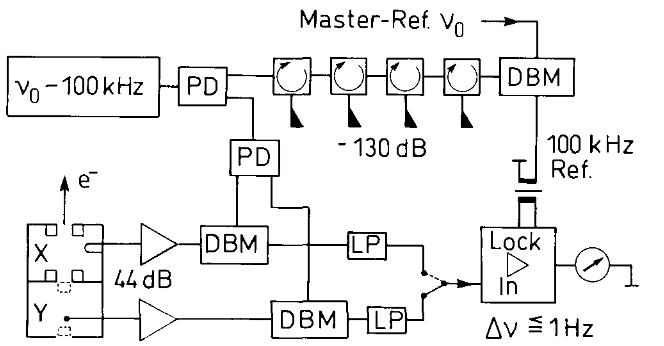

Figure 2: Setup of super-sensitive beam position monitor. At $6 \cdot 10^{-20}$ W the signal/noise-ratio is 1.5 (PD - power divider, DBM - mixer, LP - low pass filter)

10^{-18} W. In the signal processing setup (Fig. 2) a great problem was to supress any coupling from the ν_0-reference (necessary for the lock-in-amplifier) and the environs to the cavity circuit by $\geq$ 130 dB. For example the rf-leak-tightness of standard microwave components was very insufficient, they all had to be equipped at least with a second metal housing.

In the RTM's the intensity/phase- and the position-monitoring of the beam is done for all returns simultaneously. Because of lack of space we use for the x and y position-detection single symmetric resonators, both of the square TM_{210}- and the circular TM_{110}-type [4, 6]. A decoupling of -20 dB (corresponding to an error of 6° in the direction of beam deviation) between the two mode axes is easily achieved, for -30 dB a quite cumbersome fine adjustion of the symmetry is necessary. To seperate the successive beam returns these monitors must detect the τ_B = 12 nsec tune-up pulses. Detailed calculations [4, 7] showed that there are two possible modes of operation, characterized by the ratio of the cavity transient-time τ_R (defined by $W = W_0 \cdot e^{-t/\tau_R}$ for the field energy; $\omega \cdot \tau_R = Q_L$) to the beam pulse length τ_B (with $\omega \cdot \tau_B/2 = 92$ in our case). One can work either with a resonator loaded quality factor $Q_L \gg 92$ (high-Q-mode) or $Q_L \ll 92$ (low-Q-mode). The latter however has distinct advantages: for a comparable signal distortion the signal level is by a factor of three higher, the resonator is totally insensitive to detunings and, most important, if the diagnostic pulses are imposed on the cw-beam ("blackout-mode") there is much less rf-background. Because the low $Q_L \approx 30$ of these resonators is achieved by a very strong overcoupling of the antennas, their field pattern is distorted. For a TM_{010}-cavity that is quite unimportant, but in a TM_{110}-position-monitor the distortion is such, that clear field-nodelines with a phase jump of π across them do not exist anymore. The consequence would be, that the zero position of the beam as measured by the monitor-cavity would be very sensitive to the phase of the rf-reference signal at the mixer [7]. Therefore (Fig. 3) the Δ-port of a 180°-hybrid is used to get the difference of the signals from the right/left- resp. top/bottom-antenna. The output of the Σ-port of this hybrid could in addition be used for intensity monitoring. It was verified by beam measurements, that the rf-axis of these monitors coincides within 0.1 mm with their center-line. The 3 dB signal splitting, 12 nsec delay and differential recombination in a second 180°-hybrid is applied only in the blackout-mode to supress residual rf-background.

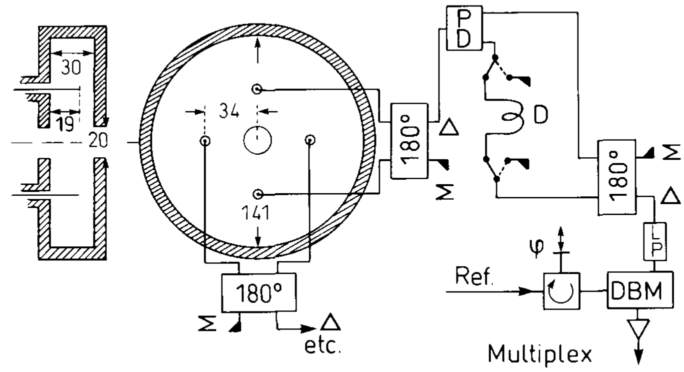

Figure 3: Low-Q pos.-monitor (D - 12 nsec delay, $\Delta\varphi = 0$)

Ferrite Current Monitors

Two types of ferrite current monitors are used in MAMI. A standard ferrite core brazed into the beam pipe is sensitive to the diagnostic pulses with a signal to noise ratio of one at 1 μA. It is used as a protective transparency monitor at a dozen points along the beamline, especially in front of and behind the RTM's, and switches off the up to 85 kW of beam power if losses exceed some percent.

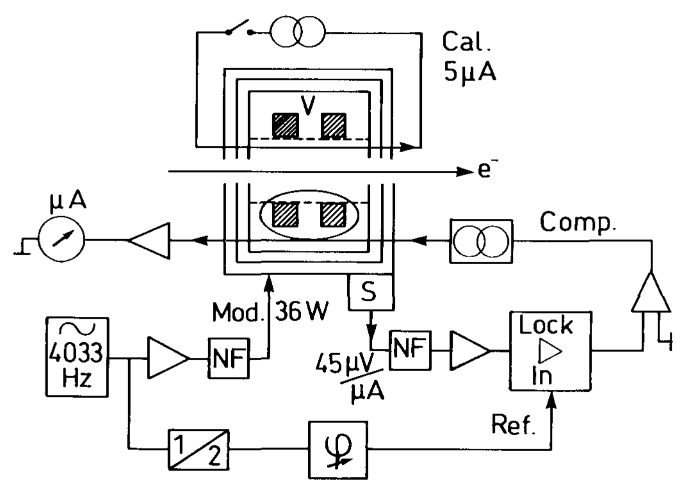

Figure 4: DCT for absolute cw-beam current measurement (NF - notch filter, S - symmetrization of double kernel V)

The second monitor (Fig. 4) is a quite sophisticated DC-current transformer (DCT) to measure the absolute cw-beam current, an essential number for the experimenters to determine their cross sections. It is based on the effect, that the strict antisymmetry of the hysteresis curve of a suitable magnetic material is lost and even harmonics come up, if there is a DC-bias field (principle of the

"Förster-Sonde"). In our DCT a double-ring-kernel of Vitrovac 6025 F (amorphous cobalt with 20% B,Si as crystallization inhibitors; Vacuumschmelze Hanau) with an inner diameter of 80 mm is used. The coils are wound such, that the fundamental and the odd harmonics of the two rings subtract, the even harmonics add. By careful adjustment and magnetic shielding a sensitivity limit of 300 nA within a 3 dB-bandwidth of 30 Hz was achieved. The limit is set by the Barkhausen-noise of the Vitrovac rings, it corresponds to the measurement of a magnetic field of $1.5 \cdot 10^{-12}$ T, i.e. 10^{-7} of the earths field. The zero point stability in a constant environment (temperature changes $< \pm 1°$, no change of stronger external magnetic fields) is better than 1 μA; an automatic zero point adjustment works if the electron beam is switched off. We use this DCT for calibration of our relative current measurement, rf-cavities resp. synchrotron radiation monitors.

Synchrotron radiation

For a diagnostic of the transverse beam matching and possible phase space distortions and couplings the knowledge of the beam profile at as many points as possible along MAMI is necessary. This is especially true for the RTM's with their weak focusing only on the linac axis. The most simple and totally non-invasive method is to observe the synchrotron radiation (SR). With cheap standard TV-cameras and a 1:1 imaging it can be observed for beam energies ≥ 50 MeV in RTM2 and average currents ≥ 1 nA behind RTM3. Therefore the return paths in these RTM's (by a mirror system and a single camera [8]) and the beam profile and position at every bending magnet in the guiding-systems behind these machines are monitored by SR.

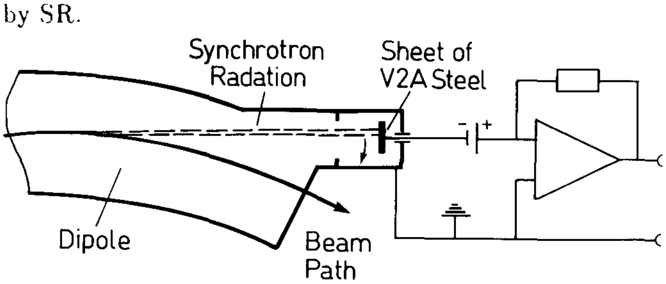

Figure 5: Synchrotron radiation current monitor

By a disturbing effect of the synchrotron radiation behind RTM3 on our wire scanners (see below) the idea came up to use the intensity of this radiation as a relative beam current monitor. For $E > 350$ MeV the SR spectrum extends well beyond 50 eV and the yield of secondary electrons from metals should be insensitive to the detailed condition of their surface. The setup is shown in Fig. 5, a sheet of roughly polished stainless steel (V2A) is used as an electrode; the DC-voltage of -27 V was applied to reject vagabonding low energy electrons. The results at 855 MeV, calibrated by a precision faraday cup, show a very good linearity and a sensitivity of 17 pA photocurrent/ 1 nA beam current. The measurement extended over several weeks, no change in sensitivity by the steady bombardment of the V2A-surface by SR was observed. Therefore this is a second very cheap and simple monitor for low cw-currents down to 1 nA, besides the TM_{010}-intensity cavities.

Diverse Monitors

Wire scanners are installed at 40 points in MAMI between and behind the RTM's to determine the beam center position and give a cut through the beam profile. They work down to currents of 100 nA at 1 mm beam diameter and their signals, after some averaging and smoothing are used by the computer for automatic beam guiding. They are not fully non-destructive and especially near the experiments must be switched off during data taking because of their background production. Behind RTM3 they were heavily disturbed by the high energy SR at any bending magnet; it hit the frame holding their 40μ tungsten wire and a broad peak of secondary electron came up. By appropriate shielding this problem was removed.

The quadrupoles on the interface-beamlines between the RTM's are, in addition to their focusing function, also used as beam monitors. Together with a scanner some distance downstream they form a device for automatic transverse emittance measurement [3]. In addition they are used as beam position adjustors: their excitation is modulated with about one Hz and, by minimizing the transverse movement of the beam spot center downstream, the electron beam is adjusted precisely to their axis.

The observation of the backward transition radiation from simple polished aluminum sheets put at 45° into the beam is possible down to some nA beam current by a standard TV-camera and can therefore replace the always "burning out" view screens made from ZnS or BeO.

To detect beam losses down to 10^{-3} and lower, 20 self-fabricated open aluminum ionization chambers with an active volume of 5 l each are installed along MAMI. They show good linearity between 3 and 20,000 μSv/h and with their threshold steer a hardware system of warnings and beam interrupts. In addition they generate a display of the quality of the beam transport via the computer.

References

[1] H. Herminghaus et al., "The Mainz Microtron – Operation Experience and Upgrade Progress", Proc. Conf. LINAC 88, Williamsburg, Cebaf-Report-89-001, p. 247

[2] H. Euteneuer et al., "Experience with the 855 MeV RTM-Cascade MAMI", Proc. EPAC 1992, Berlin

[3] H.-J. Kreidel et al., "Present State of the MAMI Control System", Nucl. Instr. & Meth. A293 (1990)p. 74

[4] B. Mertin, Diploma Thesis, Mainz 1980

[5] D. Mittwich, Diploma Thesis, Mainz 1992

[6] J. Mc Keown, "Beam Position Monitor Using a Single Cavity", IEEE Trans. on Nucl. Sci., Vol. NS-26 (1979) p. 3423

[7] H. Herminghaus, Int. Note MAMI 8/80

[8] H. Herminghaus, Int. Note MAMI 8/81