ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAL023

PULSED OPERATION AT MAMI WITH HIGH BEAM LOADING*

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Abstract

The Mainz Microtron Accelerator (MAMI) is a microtron cascade which is normally operated CW for particle physics experiments. For certain investigations it is necessary to use a pulsed beam (macro pulses, several milliseconds). Up to now this pulsed mode can only be applied if the beam loading for the accelerating RF structures is negligible. To achieve higher pulse intensities the accelerator RF infrastructure needs to be equipped with feed-forward techniques to compensate for the expected beam loading and losing part of the bunch charge. To monitor beam losses the machine protection system at MAMI needs to be extended to be able to localize fast occurrences of beam losses. This paper will present the possibilities being investigated to allow pulsed operation of MAMI within the near future.

INTRODUCTION

The Mainz Microtron (MAMI, see Fig. 1) is an electron accelerator for up to 1508 MeV at up to 100 μA operated in CW [1]. The first and oldest stage of our racetrack microtrons (RTM1) is now almost 40 years old while the newest part (the Harmonic Double Sided Microtron, HDSM) was put into operation by the end of 2006. The magnets and the RF systems are based on very reliable normal conducting technology using analog feedback loops.

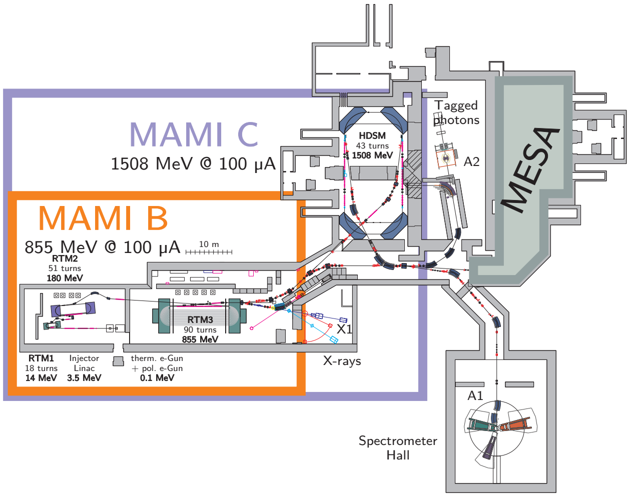

Figure 1: Floor plan of the MAMI accelerator.

So far the accelerator has been run CW for most of the experiments at many different energies along with beam currents beginning at around 1 kHz electron rate up to 100 μA.

PULSED OPERATION FOR NEW EXPERIMENTS

In order to perform further types of experiments (like the cooperation with DESY for the POSITAR experiment) the machine needs to provide pulsed beam with a macroscopic time structure. This experiment is exploring the thermal capacity of certain target materials for the POSItron TARget at ILC [2]. To imitate the expected energy depositions of the ILC positron target the 3.5 MeV injector linac of MAMI was used with pulse lengths between 1 ms and 10 ms and a duty cycle of 20 % at peak currents of 50 μA during the pulse. But at the limited energy of 3.5 MeV certain aspects of the target degradation cannot be imitated and the experiments should be repeated at 180 MeV.

Another application is to investigate different strategies to increase the beam current from 0 to maximum for future high current CW ERLs like MESA with constant bunch charge.

Macro Pulses

The pulsed mode ("macro pulses") was foreseen from the beginning of MAMI but was not intended to be used at high beam currents (i.e. more than 1 μA)[1]. The electronic equipment of the gun is not optimised for short rise/fall times which is not important for most applications. However, the beam current follows the trigger with unknown time constants. For the feedback loops of the RF systems it is very important to know the beam current/beam loading as precise as possible.

BEAM INSTRUMENTATION

Most of the diagnostic beam instrumentation at MAMI is optimised for CW operation as most experiments are run in CW mode.

RF cavity monitors The main beam diagnostics available during experimental runs are RF cavity monitors (operated in the TM_{110} mode for position and in the TM_{010} mode for phase/intensity resp.). The phase/intensity monitors would be very useful for future feed-forward applications if the bandwidth of the monitor and the electronic equipment can be increased from approx. 10 kHz at the moment to well above 1 MHz.

Beam loss monitors - ionisation chambers The accelerator is equipped with up to 32 ionisation chambers (accelerator halls and experimental halls, see Fig. 2 for MAMI-B)

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* Work supported by DFG (CRC 1044) and the German federal state of Rhineland-Palatinate

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[1] The very short "diagnostic pulses" (10 ns pulse at 100 μA, up to 10 kHz rep. rate) used to optimise the RTMs are so short to generate only an average beam loading of less than 10 nA, that is, the RF sections cannot react on the individual pulses.

for machine protection. Their main purpose is to continuously monitor the beam losses until a certain threshold is reached and the beam is switched off automatically. Usually the beam losses vary slowly over time in response to slow drifts of the beam position (ambient temperature, magnet power supply drifts etc.). Other faster beam losses may occur if some power supply fails. In any case the reaction time of the hardware interlock does not need to be faster than a few 10-100 ms – which depends also on the amount of the beam loss and the radiation. To be sensitive to beam losses as low as a few pA the analog electronic integrates the detector signals approx. 100 ms before being acquired in the control system. Therefore the system cannot be used to examine beam losses time-resolved during short macro pulses.

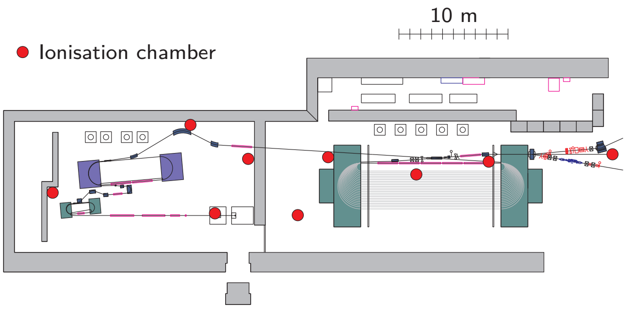

Figure 2: Installation of ionisation chambers for RTM1-3 (MAMI-B).

Beam loss monitors - scintillators For data acquisition of particle physics experiments new detector systems with scintillating fibres and multi-anode-photomultipliers are developed in house. Due to their flexible design it is planned to test a setup as beam loss monitors to provide fast and spatial resolved information. A first test with 20×2 m long fibres is planned for the end of this year at the 14 MeV stage of RTM1 to detect beam losses at each turn individually.

THE RF SYSTEM AT MAMI-B

The RF system at MAMI-B was developed more than 30 years ago and thus relies on analogue feedback loops for amplitude and phase of each individual klystron. To generate the accelerating gradient of approximately 1 MV/m the bi-periodic RF sections dissipate 15-18 kW/m in CW operation. To provide the RF power MAMI-B is equipped with 9 klystrons at 2.45 GHz. Table 1 lists the installed klystrons for each stage of the MAMI-B accelerator cascade.

Low Level RF

While the increase of RF power to accelerate 100 μA is almost negligible for the injector linac (approx. 1% only) it increases 5% for RTM1, 27% for RTM2 and 45% for RTM3. This has to be regulated by the feedback loops. Additionally each klystron/section-pair is not identical. MAMI is operated with klystrons of two manufacturers (Thales/CPI) and the waveguides, RF sections and LLRF components also have individual characteristics.

Table 1: Stages (number of turns) and the RF systems at MAMI-B with the average (per klystron) beam loading at 100 μA and the time of flight through the stage

stage (turns)	P_{RF} [0 μA]	B.L. (100 μA)	ToF
ILAC (1)	1 x 50 kW	1 × 350 W	<0.1 μs
RTM1 (18)	1 x 20 kW	1 × 1050 W	0.3 μs
RTM2 (51)	2 x 30 kW	2 × 8300 W	2.5 μs
RTM3 (90)	5 x 30 kW	5 × 13500 W	10.0 μs

While the amplitude and phase is controlled by fast electronic attenuators and phase shifters at the RF input of each klystron ($f \approx 10$ kHz), the resonant frequency (and also the phase) of each section is tuned by slow mechanical plungers ($f \approx 1$ Hz). This results in very different characteristic frequencies of each feedback loop.

For normal operation this is not critical because the beam current usually is increased manually and slower than 1 μA/s to be able to react on failures. Decreasing to 0 μA is also not critical as there is no beam to experience unmatched RF power. But decreasing fast from high current to intermediate current eventually leads to interlocks by the beam loss monitoring system due to unmatched RF power which may cause synchrotron oscillations with amplitudes larger than the acceptance.

The time of flight through each stage of MAMI also needs to be taken into account. For RTM3 the ToF amounts approx. 10 μs. That means that the beam current increases from 0 to peak within this time (i.e. until all 90 recirculations have been reached after approx. 10 μs ToF).

FIRST TEST AT MAMI

During a machine test beam time the pulsed operation was tested at different peak beam currents and different pulse lengths. Up to 10 μA peak current the LLRF feedback systems seem to perform quite well to deliver the full pulse charge at the beam dump for 855 MeV (estimated from the low readings of the BLMs during a sequence of pulses at 10 % duty cycle).

Figure 3 shows the signals of the first RF cavity monitor at 100 keV electron energy for pulses from 20 μA up to 100 μA. The signals behave as expected and increase linearly with increasing peak current. The rise time of approx. 50 μs however cannot distinguish between the real change of beam current and the limited bandwidth of the monitor electronics. This will be studied in the near future. Unfortunately the RF monitors for phase and intensity at higher energies did not work as expected and could not be used as an indicator for beam transmission.

Behavior of the LLRF Systems

In addition to the RF monitors the LLRF system of the klystron/section pairs was investigated during the beam test. The expected relative beam loadings (see Tab. 1) could be verified approximately at peak currents of 10 μA (Fig. 4).

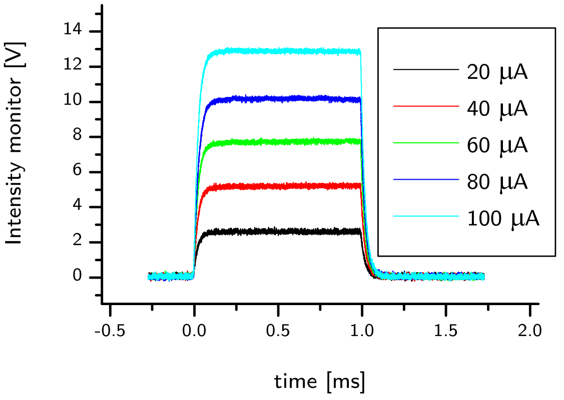

Figure 3: Beam current signals of the first RF cavity monitor for single macro pulse of 20-100 μA peak current and 1 ms length (data sampled at 5 MS/s).

The fundamental trend of each RF power curve is also very similar compared to the beam intensity measurement shown.

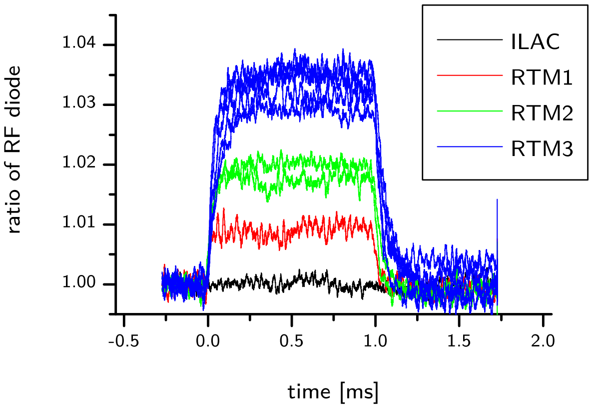

Figure 4: Relative change of the RF diode voltages (wave guide forward power) for a single macro pulse of 10 μA peak current and 1 ms length (data sampled at 5 MS/s, averaged over 10 μs).

If the peak current is increased to 50 μA the picture changes quite drastically (see Fig. 5). While for RTM1 everything still seems to be fine, already for the two LLRF loops of RTM2 the pulse shape breaks down after approx. 0.7 ms. This effect can be seen even stronger in RTM3 where the break down occurs much earlier. The most probable reason for this effect are beam losses occurring between 14 MeV and 855 MeV which corresponds to increased readings of the BLMs during a sequence of pulses.

CONCLUSION

It has been demonstrated that pulsed beam is possible with MAMI only at the lowest energy of 3.5 MeV if macroscopic pulse lengths and high peak currents of more than 50 μA are used. For RTM1 (14 MeV) 20-40 μA seem possible without larger modifications. However, for higher energies of 180-855 MeV the peak current is limited to approx. 10 μA using macro pulses.

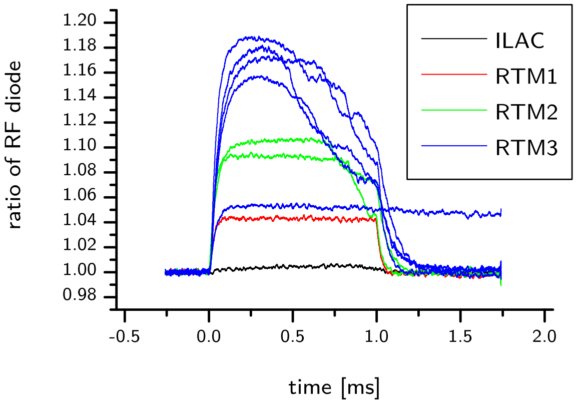

Figure 5: Relative change of the RF diode voltages for a single macro pulse of 50 μA peak current and 1 ms length (See also Fig. 6 for a close-up into the start of the pulse).

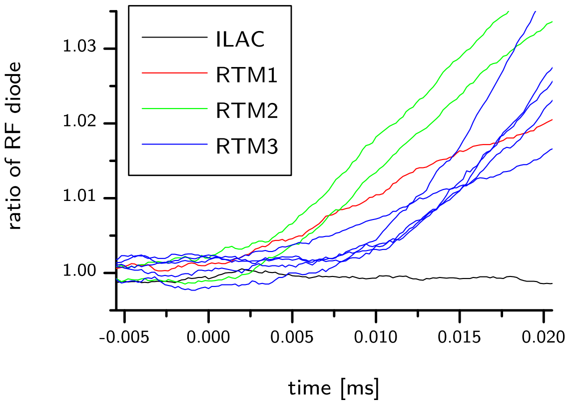

Figure 6: The LLRF systems for the different stages react on the beam loading after the ToF of the preceding microtron stages (Most obvious the beam reaches RTM3 approx. 3 μs after RTM2).

To overcome these limits new RF feedback loops have to be installed. For better control of beam losses also a faster system of BLMs is currently developed for a new detector setup in the spectrometer hall of MAMI and will be tested at RTM1.

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