ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPGW008

FIBER BEAM LOSS MONITORS AT MAMI*

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Abstract

At the 14 MeV stage of the 1508 MeV cascaded racetrack microtron accelerator Mainz Microtron (MAMI) fiber beam loss monitors with multi-anode photomultipliers (ma-PMTs) have been successfully tested. The combination of individual fibers for each recirculation beam pipe with ma-PMTs allows to detect beam losses turn by turn in the order of 10^{-4} or even lower which cannot be accomplished with the already existing beam diagnostics. This kind of beam loss monitor might be an alternative to ionisation chambers for the new Mainz Energy Recovering Superconducting Accelerator (MESA).

INTRODUCTION

The Mainz Microtron (MAMI) is an electron accelerator for up to 1508 MeV at up to 100 µA operated in CW [1]. Directly next to this accelerator the Mainz Energy-Recovering Superconducting Accelerator (MESA) will be built soon. This new accelerator will deliver up to 105 MeV electrons with the multiturn ERL mode at up to 1 mA beam current or 155 MeV polarised electrons at up to 150 µA for experiments with external beam [2].

The development of many devices foreseen for MESA does benefit a lot of the MAMI accelerator which can be used as a testing facility. This begins with very simple components like luminescent screens and ends with complex detector systems which will be used for the experimental data acquisition.

Detectors and Monitor Systems

One of these systems is the fiber detector system which was originally developed for the Kaon spectrometer (KAOS) at MAMI [3]. Together with four multi-anode photomultipliers (Hamamatsu R7259K(S)) with HVSys512 HV supply, the detector system was extended with 16 NINO ASICs [4] and four FPGAs. As many as 128 channels can be combined in a very flexible configuration (i.e. in coincidence with an external trigger or coincidence between different fibers) [5]. At MESA a dedicated setup consisting of a few of these systems will be used within the MAGIX experimental setup and the beam dump experiment (DarkMESA) [6].

However, the demands for beam diagnostic elements for the MESA accelerator also makes new developments necessary. To prevent damages by beam losses at MAMI a dedicated system of up to 32 ionisation chambers is used to continuously monitor beam losses. This system is very robust (full beam loss at 100 µA) and at the same time very sensitive (down to a few pA).

The (slow) analogue readout and interlock generator presently used at MAMI complicates the observation of time-correlated or transient events. For MESA this may be important for helicity correlated beam losses while the accelerator is run with polarised electrons during parity violating electron scattering experiments or during pulsed operation to ramp up the beam current in ERL mode.

While being relatively small (approx. 50×35×5 cm^3) they have been mounted at strategic positions where beam losses are likely to occur (for example at the end of the linac axis of the microtrons). Figure 1 shows the position of the two important ionisation chambers in Hall A. The beam losses of the fiber system is compared to the beam losses detected by these ionisation chambers.

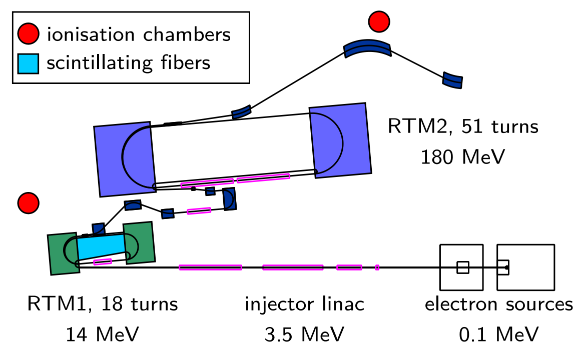

Figure 1: Position of the two ionisation chambers chambers with respect to the beam line and the accelerator components in Hall A of MAMI and the area with the fibers at the RTM1.

TEST INSTALLATION AT MAMI

To test and improve this detector system it has been installed at the first stage of the MAMI accelerator (at the 14 MeV RTM1, see Fig. 1). The experimental setup covers the 3.5 MeV injection and seventeen return paths of the RTM1. For simplicity the fibers have been loosely attached on top of the vacuum system to be able to remove everything later without destroying parts (see Figs. 2 and 3).

Analogue Signals

The fibers have been connected to the PMT directly. The PMT was operated at -850 V which gave reasonable signals even at lowest beam loss rates. Between the PMT and the four NINO ASICs two 16 channel buffer boards were installed (gain factor of 2) to split the signals for an analogue output and for the NINO ASICs. This allows to discriminate all 32 channels of the PMT (only 18 of them are used).

Using external DACs the thresholds of the NINO ASICs have been optimised to get lowest counting rates without

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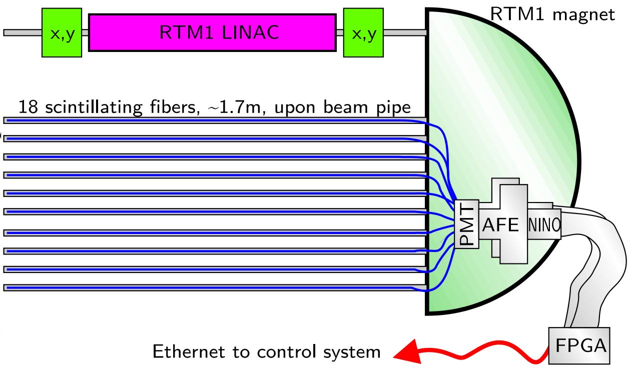

Figure 2: Schematic drawing of the detector system [5] (PMT: photo multiplier, AFE: analogue front end).

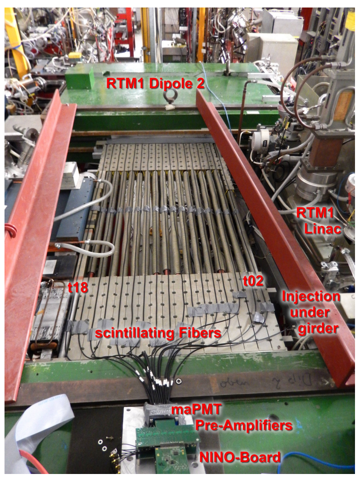

Figure 3: Photo of the fibers attached to the return paths of RTM1 [5]. Linac on the right side, turn 1 (injection) under the red girder, then turn 2–18 from right to left.

beam. The output pulse length has been lengthened by 45 ns to be easily detectable by the FPGA logic.

Digital Signals

The output signals of the NINOs are fed into an FPGA logic which was originally developed for particle detection providing flexible coincidences, see Fig. 4. For the beam loss measurements presented here the coincidences have been disabled to just count the individual rates of each fibers.

MACHINE OPERATION

All microtron stages of MAMI are equipped with RF cavity monitors (BPM) on the linac axis (see Fig. 1). This allows a turn-by-turn beam position measurement only if pulsed beam is used (diagnostic pulse, 10 ns long, 100 µA peak, 10 Hz–10 kHz rep. rate).

During physics experiments the beam is usually used CW (i.e. every RF bucket is filled with electrons). The BPMs on the linac axis cannot be used any more because the bunches of all recirculated beams enter the BPM in the same moment.

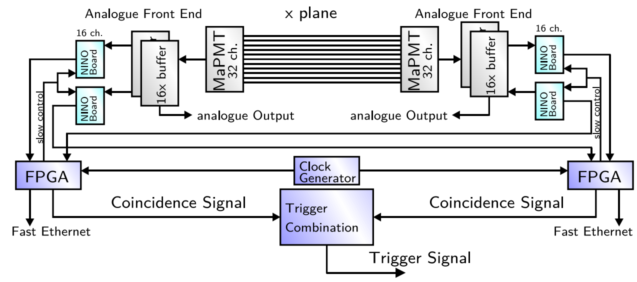

Figure 4: Block diagram of the data acquisition system. The FPGA board (MYiR Z-turn with Xilinx Zynq-7220, 100 MHz) is used to perform the coincidences, to count the individual and coincidence rates, to generate regions of interest, and to adjust the thresholds and pulse widths of the NINO Chip. Events can be accumulated with timestamps in an event builder. Read out is done via fast Ethernet. Only half of the electronics were used for the measurements.

In addition to the beam losses the beam position can be monitored only at a few places along the beam lines between the different stages and towards the experimental halls.

This is not critical as the accelerator runs very stable a few hours after it is started. Slow drifting of the magnet systems or the RF systems will cause slow changes of the beam position which again lead to variations of the continuously monitored beam losses. If these beam losses reach certain thresholds the accelerator is optimised by the operator.

Beam Tests

Main goal of the test setup was to continuously monitor beam losses at the 14 MeV stage (RTM1) during routine operation over several weeks. It would be interesting to see if variations of the beam losses could be correlated with other parameters (like cooling water temperature, hall temperature, or alike).

The time period covered a beam time with several optimisations of the accelerator and the normal operation with beam currents of 10 µA up to 20 µA for the physics experiment in the spectrometer hall.

The top plot of Fig. 5 shows the beam current during the physics experiment for almost two weeks and the beam losses. The two ionisation chambers in Hall A show a rather constant ratio of beam losses against beam current in the first week whereas during the second week the ratio increases. A similar behaviour can be observed with the scintillating fibers of the RTM1 (bottom of Fig. 5). Interestingly the average count rates of the first nine turns of RTM1 stay rather constant while the rates of turns 10 to 18 tend to increase much stronger.

Figure 6 shows the effect of a routine optimisation of the accelerator. Until approx. 16:40 the beam losses constantly grow as indicated by the fibers and the ionisation chambers. The drift is caused mainly by the warming up of the accelerator after beginning the beam time for the physics experiment in the spectrometer hall. Until 17:40 the machine (i.e. the

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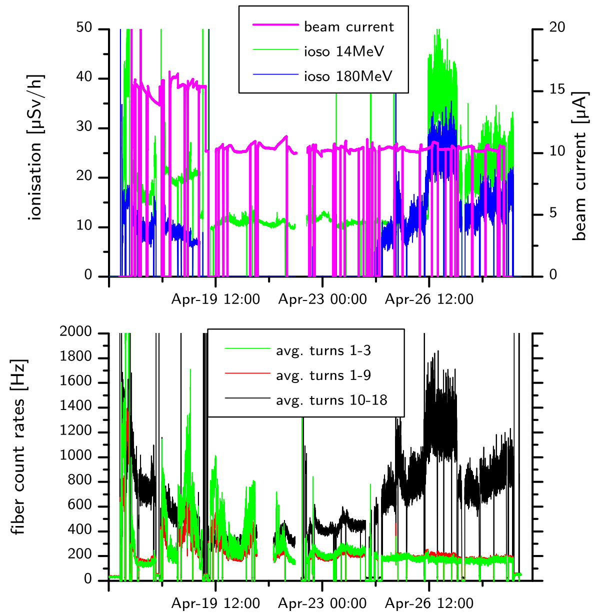

Figure 5: Beam losses at RTM1. Top: beam current and ionisation chambers in Hall A of MAMI. Bottom: Average count rates of turns 1–3, turns 1–9 and turns 10–18 of the fibers developing in different directions.

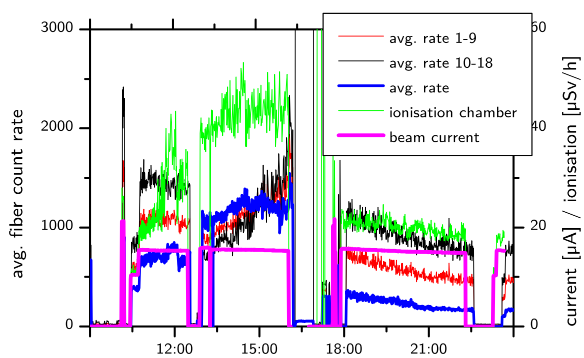

Figure 6: Comparison of the beam losses detected with the ionisation chamber (green) and the average count rates of the fibers for turns 1–9 (red) and turns 10–18 (black) on the first day.

beam positions in all microtron stages and the phases of the accelerating RF voltages) has been optimised using low average beam current (up to 10 nA, diagnostic pulses). The remaining period of that day still shows a change of the beam losses but at much lower rates.

A different situation is presented in Fig. 7. Here, the correlation between the cooling water temperature of MAMI and the corresponding beam losses is obvious. The count rates of all fibers rise in a similar shape. The ionisation chamber also detects larger beam losses but the fiber detector gives a much more detailed picture of this period.

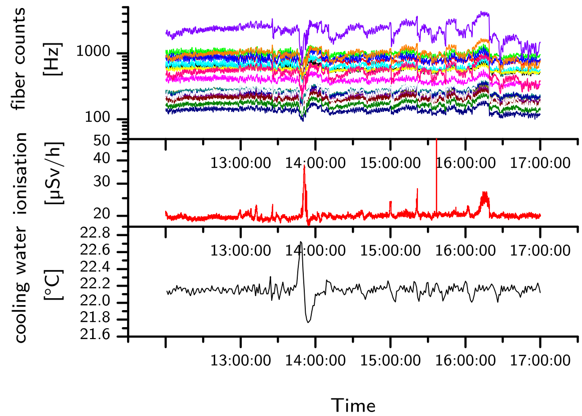

Figure 7: Count rates of the 18 fibers mounted on RTM1 compared to the ionisation chamber at 14 MeV and the cooling water temperature.

CONCLUSION AND OUTLOOK

The fiber beam loss monitor proves to be a reasonable alternative for the new MESA accelerator compared to the ionisation chambers. The flexible configuration of the FPGA readout as beam loss monitor has not yet been fully utilised but offers many interesting possibilities in conjunction with future experiments at MESA (i.e. helicity correlated beam losses). The fibers will stay installed for the near future at RTM1 at MAMI to study the possible degradation due to radiation as well as to monitor the beam losses continuously.

REFERENCES

[1] K.-H. Kaiser *et al.*, “The 1.5 GeV harmonic double-sided microtron at Mainz University”, in *Nucl. Instr. and Methods in Physics Research*, vol. 593, issue 3, Aug. 2008, pp. 159–170. http://dx.doi.org/10.1016/j.nima.2008.05.018

[2] F. Hug *et al.*, “MESA - an ERL Project for Particle Physics Experiments”, in *Proc. LINAC'16*, East Lansing, MI, USA, Sep. 2016, pp. 313–315. https://doi.org/10.18429/JACoW-LINAC2016-MOP106012

[3] P. Achenbach *et al.*, “A large-scale FPGA-based trigger and dead-time free DAQ system for the KAOS spectrometer at MAMI”, in *IEEE Trans. Nucl. Sci. 58*, pp. 1677–1684, 2011.

[4] F. Anghinolfi *et al.*, “NINO: An ultra-fast and low-power front-end amplifier/discriminator ASIC designed for the multigap resistive plate chamber”, in *Nucl. Instrum. Methods in Physics Research*, vol. 533 (2004), pp. 183–187. http://cds.cern.ch/record/818554

[5] M. Mauch, “Entwicklung und Einsatz eines FPGA-basierten Trigger-Systems an MAMI”, Master Thesis, Institut für Kernphysik, Mainz, 2019.

[6] L. Doria *et al.*, “Search for light dark matter with the MESA accelerator”, in *13th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2018)*, Palm Springs, California, USA, May 29–June 3, 2018. https://arxiv.org/abs/1809.07168