

THE MAMI-C ACCELERATOR: 25 YEARS OF OPERATION AND STRATEGIES FOR THE NEXT DECADE*

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Abstract

The Mainz Microtron Accelerator (MAMI-C) is a staged Race Track Microtron (RTM) accelerator for 100 μA polarised electrons up to 1.6 GeV energy [1]. This report addresses the problems and our strategies to reliably operate the MAMI-C Accelerator for at least another ten years and what lessons have been learned for the new Mainz Energy recovering Superconducting Accelerator (MESA).

INTRODUCTION

The MAMI accelerator (Fig. 1) is based on very reliable normal conducting technology for magnets and RF systems. Since the beginning of operation in 1990 the first three microtrons up to 855 MeV have been operated more than 155000 hours at 5000-7000 hours per year. The double-sided microtron (HDSM) has been put into operation at the end of 2006 and started routine operation for experimental physics runs in February 2007. Since then it has been used for more than 30000 hours.

spectrometer hall for electron scattering research and Kaon production [2, 3], the A2 facility for tagged photons [4] for experiments with real photons and the X1 setup for radiation generation experiments and a wide range of detector tests [5]. The A4 experiment for parity violating electron scattering [6] has been dismantled in favour of the new accelerator project MESA [7] which is going to be set up in these experimental halls together with another adjacent new building presumably starting around 2020.

To fulfill the demanding requirements of the different experiments MAMI is equipped with a thermionic electron gun for routine operation and another gun for longitudinally polarised electrons which needs more workload due to refreshing the GaAs cathodes every 3-6 weeks [8]. This gun was recently used to conduct a series of experiments using vertically polarised electron beam with MAMI-B [9].

The beam energies routinely available for experiments begin as low as 180 MeV up to 855 MeV for MAMI-B every 15 MeV, from 871 MeV to 1308 MeV in steps of approximately 15 MeV and the final energy of 1508 MeV. Intermediate energies can be delivered by tuning the magnetic fields of the microtron cascade which enables MAMI to cover the complete energy range from 160 MeV up to 1604 MeV [10–12]. The usage of the different energies is illustrated in Fig. 2.

For small scale experiments (i.e. polarimetry, irradiation tests) two other sites are available behind the injector linac with kinetic energies between 1 MeV and 3.7 MeV and following the first microtron RTM1 at 14 MeV [13, 14].

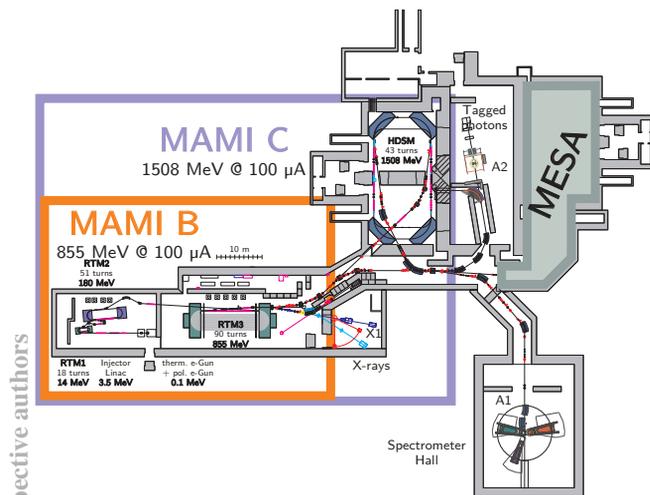


Figure 1: Floor plan of the MAMI accelerator.

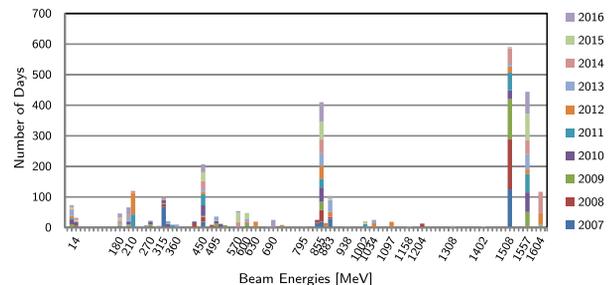


Figure 2: Beam energies delivered for the last ten years.

PRESENT STATUS AND OPERATIONAL ISSUES

Since 2012 a new long term funding scheme has been granted which includes a demanding physics programme with the high quality electron beam of MAMI. Three major experimental areas can be served by MAMI: the A1

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MOST SEVERE PROBLEMS

The accelerator proves to be very reliable in spite of the age and failures of some of the components. The average downtime due to accelerator related failures is approx. 4% for the last 10 years at an average of 6420 hours of operation. The distribution of different failures is shown in Fig. 3.

Setup, shutdown and optimisation of MAMI and beam lines required approx. 13.5 % with a maximum of 19 % in 2007 when the HDSM was commissioned for routine operation.

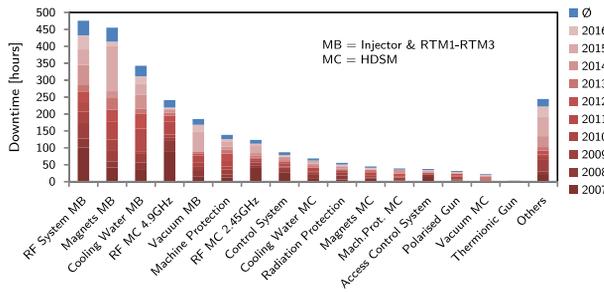


Figure 3: Failures of the MAMI accelerator accumulated for the last ten years.

The magnets of the first two stages (RTM1 and RTM2) are older than 30 years now. The cooling water circuits have partly been bypassed due to small irreparable leaks in the coils. Also one of the two correction coils made of a printed circuit board of one of the dipole magnets of RTM2 has lost some of the contacts to provide the nominal currents [15]. However the remaining correction strength (approx. 2/3 of the nominal area of correction) is good enough to operate MAMI without restrictions concerning the phase of the recirculated beams, deflection angle errors or undesired defocussing properties. Since the first occurrence of this failure in 2012 the fault did not become worse.

At the HDSM one critical water leak concerning the 4.9 GHz RF systems occurred at the tip of one tuning plunger. The water flow direction for all twenty plungers of the 4.9 GHz RF sections was checked and connected reverse to minimise the abrasion of the other plunger tips. Additionally the water flow was reduced from 140 l/h to approx. 60 l/h which is the limit of the water flow meters used to indicate water flow failures and RF interlocks.

For other leaks our mechanical workshops have prepared a number of spare parts to be able to replace the affected parts very fast. This is commonly the case for transistor cooling banks and the water piping of the MAMI-B RF sections. Usually the defective copper piping can be replaced by stainless steel in less than one hour.

BUILDING SERVICES MANAGEMENT SYSTEM

The building services management system is partly maintained by the workshops of the institute, the university and the owner of the buildings. Most power components (pumps, fans etc.) are 30 years or even older but work reliably. The complex automation system by Siemens was introduced in 2001 and carefully adjusted to meet the required stability of $\pm 0.1^\circ$ for the cooling water.

Cooling Water Flow Reduction

To reduce the number of water leaks at least for the HDSM (which is used between 3000 and 4000 hours per year) the

water flow is reduced to approximately 10 % during the shutdown periods. This has been achieved by installing frequency converters for the main water pumps. Up to now there is not enough statistics to reliably tell the difference of water leaks before and after this measure but it is expected to double the remaining life time of water cooling circuits.

Another measurable benefit of installing the frequency converters results in a better efficiency of the wet cooling tower plant during hot or humid weather periods. The water flow can be adjusted exactly to what is needed and results in a higher temperature spread between inlet and outlet. This also yields a better stability of the cooling water temperature. Being very successful a similar system has recently been installed for the cooling plant of the A1 spectrometer hall also to minimize the risk of newly occurring water leaks.

Updating the Building Automation System

Since 2011 the software and hardware is not maintained by Siemens any more and no replacement parts are available. For that reason all controllers and the complete software for our building services management system need to be replaced by an up-to-date version of the controllers and software product. This is very critical: the cooling water temperatures need to be as stable as $\pm 0.1^\circ$ and for radiation protection reasons also continuous venting of the accelerator and experimental halls is mandatory. To reduce the necessary downtimes of the accelerator the replacement is performed gradually for low priority controllers and at once for the most important (i.e. cooling water) controllers within one month.

KLYSTRON INFRASTRUCTURE

The MAMI accelerator is operated with 19 klystrons: one for the injector, one for RTM1, two for RTM2, five for RTM3 (i.e. 7x 2.45 GHz Thales TH2075 and 2x 2.45 GHz CPI VKS7960M) and ten for HDSM (5x 2.45 GHz TH2174, 5x 4.9 GHz TH2166, all Thales) [16]. The average operating hours of the nine klystrons for MAMI-B amount to approx. 75000 hours, with the oldest klystron running for almost 160000 hours. To achieve as high as possible operating hours the klystrons are usually run with a very low heating power, just enough to provide a stable current from the cathode but well below specification. That is done to reduce the amount of evaporating barium off the cathode.

The average operational time of defective klystrons amounts to approx. 51000 hours with the main reason of failure being bad vacuum followed by multipacting. Quite recently we had to replace two klystrons (CPI 2.45 GHz, Thales 4.9 GHz) due to water leaks at the vacuum window to the wave guide. The first attempt to repair the 2.45 GHz klystron seems to be successful. It was run at full RF power into a water load for more than two days at the in-house klystron test facility and will soon be put into regular operation again.

From the number of defective klystrons (14x 2.45 GHz, 3x 4.9 GHz) over 25 years it can be estimated that one klystron

every two years might fail. Taking into account the relatively high average operation hours the loss of one klystron per year seems to be more realistic.

Replacing a klystron of the same vendor can be organised in less than one day, changing from CPI to Thales or vice versa for 2.45 GHz requires more preparation if a suitable klystron is available in house. For that reason we have a number of 2.45 GHz klystrons and two 4.9 GHz klystrons on stock. As there is only one manufacturer for the latter we decided to order two more klystrons which now have been delivered.

STRATEGIES FOR THE NEXT DECADE

Even after 25 years of operation exciting physics questions are still pursued with the MAMI accelerator. A lot of beam energies are available at MAMI and the beam quality (emittance, stability, availability and flexibility) is well known by most experimenters. The accelerator is of fundamental importance for the physics programme of the ongoing CRC 1044 ("The Low-Energy Frontier of the Standard Model: From Quarks and Gluons to Hadrons and Nuclei") and partly for the cluster of excellence PRISMA ("Precision Physics, Fundamental Interactions and Structure of Matter"). Furthermore it also acts as a very attractive test site for e.g. detector development of collaborating laboratories.

Ongoing Refurbishment Measures

To operate MAMI as reliably as during the last decade there are a few refurbishment measures continuously ongoing. Old water conduits made of copper with small bending radii are replaced by stainless steel or simple water hoses (The very low beam losses at MAMI allow the use of simple and cheap household components). Most of these refurbishments can be performed on regular maintenance days.

The number of severe failures has not been growing significantly within the last ten years. The combination of beam times lasting for one or two weeks for experiments followed by one day for maintenance proves to be a reasonable trade-off between the strain for the accelerator components and the reliability of the whole system.

To achieve a comparable reliability for MESA, the most prominent failures of MAMI should be avoided. The RF system based on solid-state amplifiers and superconducting cavities will be completely new. But the next most severe problems arising from magnets (power supplies and defective coils) as well as cooling water will be considered for the design of new components and the cooling.

The significant support of the university together with the world wide connected physical experiments community enables a very autonomous operation also for the next years. This is also expressed by the support to build and operate another powerful accelerator in parallel to MAMI at Mainz university: MESA.

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.
- [2] K. I. Blomqvist *et al.*, "The three-spectrometer facility at the Mainz microtron MAMI", in *Nucl. Instr. and Methods in Physics Research*, vol. 403, issue 2–3, Feb. 1998, pp. 263–301.
- [3] P. Achenbach *et al.*, "Front-end electronics for the KAOS spectrometer at MAMI", in *IEEE Trans. Nucl. Sci.* 56 (2009) pp. 316–319.
- [4] J. C. McGeorge, *et al.*, "Upgrade of the Glasgow photon tagging spectrometer for Mainz MAMI-C", in *EPJ A* (2008), doi:10.1140/epja/i2007-10606-0
- [5] H. Backe, *et al.*, "Forward diffracted parametric X radiation from a silicon single crystal", in *Nucl. Instr. and Methods in Physics Research*, vol. 234, issue 1–2, May 2005, pp. 138–147.
- [6] S. Baunack *et al.*, "Measurement of strange quark contributions to the vector form factors of the proton at $Q^2=0.22$ (GeV/c)²", in *Physical Review Letters* 102:151803, 2009, arXiv:0903.2733
- [7] R. Heine, K. Aulenbacher, and R. Eichhorn, "MESA - Sketch of an energy recovery linac for nuclear physics experiments at Mainz", in *Proc. IPAC'12*, New Orleans, LA, USA, May 2012, paper TUPPR073, pp. 1993–1995.
- [8] K. Aulenbacher *et al.*, "The new polarized beam injection at MAMI", in *Proc. EPAC'98*, Stockholm, Sweden, June 1998, paper MOP02E, pp. 1430–1432.
- [9] B. S. Schlimme *et al.*, "Vertical beam polarization at MAMI", in *Nucl. Instr. and Methods in Physics Research*, vol. 850, issue, April 2017, pp. 54–60.
- [10] R. Heine *et al.*, "Recent status of the MAMI-C accelerator and first experiences with the energy upgrade towards 1.6GeV", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper THPD025, pp. 4328–4330.
- [11] M. Dehn, K. Aulenbacher, K.-H. Kaiser, H.-J. Kreidel, and V. Schmitt, "Downscaling the energy of the MAMI-B cascade towards 100MeV", in *Proc. IPAC'13*, Shanghai, China, May 2013, paper TUPWO014, pp. 1910–1912.
- [12] M. Dehn *et al.*, "Recent challenges for the 1.5 GeV MAMI-C accelerator at JGU Mainz", in *Proc. IPAC'16*, Busan, Korea, May 2016, paper THPOY026, pp. 4149–4151.
- [13] P. Heil and S. Riemann, "High energy density irradiation with MAMI LINAC", presented at the IPAC'17, Copenhagen, Denmark, May 2017, paper TUPAB003, this conference.
- [14] F. Nillius and K. Aulenbacher, "Vector polarimetry at MaMi – Measurements of tensor correlation coefficients in e⁻ bremsstrahlungs processes", in *Journal of Physics: Conference Series* 298, 2001.
- [15] H.-J. Kreidel *et al.*, "Sustaining the reliability of the MAMI-C accelerator", in *Proc. IPAC'12*, New Orleans, LA, USA, May 2012, paper THPPR027, pp. 4023–4025.
- [16] R. Heine and F. Fichtner, "The high power RF systems of MAMI and MESA", in *CWRF 2016*, Grenoble, France, June 2016.