# SUSTAINING THE RELIABILITY OF THE MAMI-C ACCELERATOR*

H.-J. Kreidel, K. Aulenbacher, M. Dehn, F. Fichtner, R. Heine, P. Jennewein, W. Klag, U. Ludwig-Mertin, J. Röthgen, V. Tioukine
Institut für Kernphysik (IKP), University of Mainz, Germany

*Abstract*

A status report of the 1.6 GeV electron accelerator MAMI is given together with an outlook towards its future operation. We describe problems which are imposed by some aging technical subcomponents in the first stages which have in part been in operation for almost 30 years. We present measures how to sustain the achieved extremely high reliability during the upcoming new research programs which are foreseen to last at least for one more decade.

## INTRODUCTION

MAMI (Fig. 1) is a normal conducting CW electron accelerator consisting of a pre-accelerator, three cascaded race-track microtrons (RTM) and, as last stage, a harmonic double-sided microtron (HDSM) [1]. Its history was as follows: In 1983 the first two microtrons delivering 180 MeV electrons were set into operation (called MAMI-A). In 1990 the 855 MeV-microtron stage was finished (MAMI-B) and finally, in December of 2006, the HDSM was completed (MAMI-C), delivering up to 1.6 GeV electrons at a maximum current of 100 µA. MAMI-C has proved to be a very reliable machine. It routinely operates for more than 6000 hours per year and the availability for users is about 85% of this time. Less than 4% of the operation time is downtime due to failures in the accelerator or its infrastructure. The total operating time since 1991 amounts to 123,000 hours.

In 2011 support for new long-range research programs at MAMI has been granted by the funding authorities.

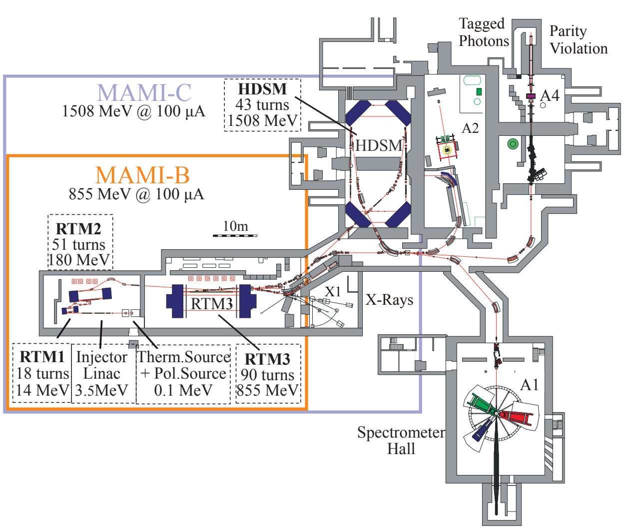


Fig.1: Floorplan of the MAMI facility

* Work supported by DFG (CRC 443/1044) and the German federal state of Rheinland-Pfalz

Within the recently founded collaborative research center (CRC 1044) – devoted to explore the limits of the standard model by electron scattering experiments – MAMI-operation is foreseen to continue for the next ten years.

In this paper we first summarize the present situation and recent developments. After discussing the components which seem most prone to aging problems, we sketch our strategy how to maintain a high reliability in spite of the fact that several components will approach a lifetime of half a century.

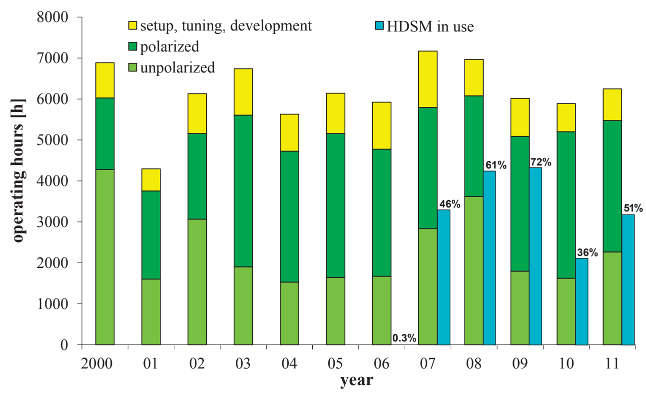


Fig.2: Operation statistics

## PRESENT STATUS

The MAMI-accelerator serves 4 experimental sites: the 3-spectrometer setup and the KAOS-spectrometer [2] for electron scattering research and Kaon production (A1), the photon tagging facility [3] for experiments with real photons (A2), the parity violation experiments [4] (A4) and the X-ray radiation sources research (X1). MAMI is equipped with two electron guns. Firstly a thermionic gun provides a convenient means to supply a high quality beam in an extremely reliable fashion. For experiments which require spin-polarisation or specific conditions - such as single bunch operation - a GaAs based photo source is available [5]. This device is only operated when needed (up to 60% of beam time) in order to minimize workload and downtime which are caused by its considerable complexity. The energy range reaches from 160 MeV to 910 MeV by the MAMI-B cascade and from 871 MeV up to 1604 MeV by the HDSM. This last stage was originally designed for an output energy of 1.5 GeV, but by means of an energy upgrade program, it was possible to exceed the design value [6]. This is advantageous for the near-threshold production of heavy mesons where even a small relative boost in beam energy increases the event rate considerably or may even allow to overcome the production threshold. It is therefore to be expected

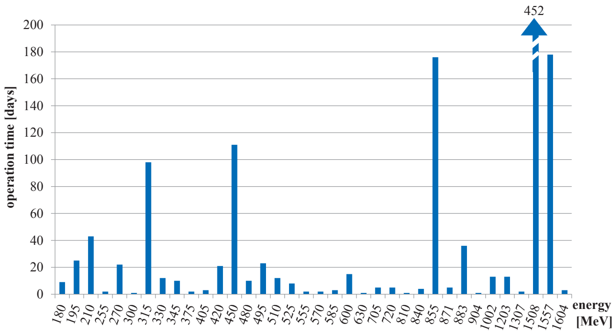


Fig. 3: Beam energies delivered for experiments in the period 2007 to 2011 in days.

that most experiments dealing with the aforementioned mesons (10-20% of the total run-time) will be done with energies exceeding the initial design value. For special purposes also electron energies between 2 and 4 MeV and also 14 MeV have been delivered. Common energies requested by the experimenters were 855 MeV, 1.508 GeV and 1.557 GeV, but also a considerable fraction of lower energies (Fig. 3). Fig. 2 shows the operating time during the last 12 years classified into the different operating modes: spin-polarised beam, non-polarised beam and machine setup. Also the percentage of MAMI-C operation is depicted. The majority of beam time was performed with polarised beam; in roughly the half of the total beam time the HDSM was in operation, in most cases with energies equal or more than 1.5 GeV.

A couple of beam stabilisation systems have been installed to enhance beam quality. Extraction energy stabilisation systems for RTM3 [7] and HDSM [8] were developed in 1999 and 2009 respectively, which reduce beam energy fluctuations to $10^{-6}$ by shifting the RF-phase of the linac. These systems are by now very reliable and are used in routine operation. A multi-level beam position stabilisation has been installed to fix the beam position on the A4-target with a precision of better than 0.01 mm. For this purpose in two sections of the beam line leading to the experiment pairs of beam monitors and beam steerers are used to maintain position and angle of the beam. Both systems have a fast part (beam fluctuations from 1 Hz to 10 kHz) using specially crafted steerers with a beam pipe made of glass and a slow part using standard steerers with

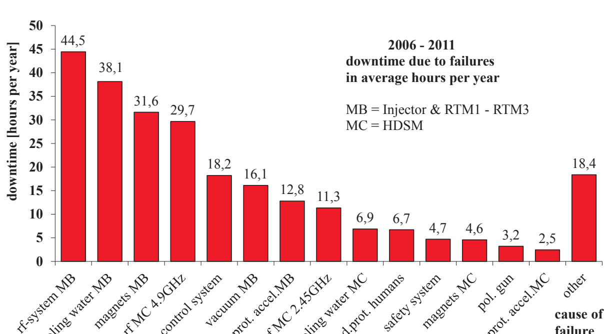


Fig. 4: Downtime classified into reasons of failure in the past 6 years. The average overall downtime sums up to 249 h/year which is 3.9% of the total operating time.

iron yokes. This sequence of stabilisation systems suppresses the beam fluctuations by more than a factor of 100. A similar system is currently commissioned for the A1-target. Finally a beam current stabilisation system controls the power of the laser beam on the photocathode of the polarised gun with respect to the signal of an electron-beam-intensity RF-monitor downstream the gun. This system very effectively suppresses also slight intensity changes caused by the helicity switching in parity violation experiments. It also compensates for long-term drifts due to surface effects in the emitting strained layer GaAs photocathode [5]. All these systems are operated very successfully and enhance beam quality considerably.

## POWER SUPPLIES AND KLYSTRONS

An aspect to be considered concerning the reliability of the facility is the large number of over-aged power supplies. So far, breakdowns were mainly caused by dry electrolytic capacitors, fan failures, leakage in a cooling water pipe or a worn out variable transformer. The supplies with less power (up to 1.5 kW) can be easily exchanged by up-to-date standard devices. The stronger ones must be kept in operation by preventive maintenance: The fans are exchanged periodically and suspicious capacitors are tested; for some types of power supplies replacement cooling water installations have been prepared. The variable transformers in ancient supplies are checked and repaired periodically. However, for some high power supplies (e.g. the supply to power both dipoles of the 3rd microtron serially) no backups are available and a major failure could result in a sustained outage of the facility.

For supplying the klystrons two 100kW and one 900kW 30kV-supplies are present in MAMI-B. The very over-aged (36 resp. 42 years old) 100kW devices supply the injection linac and the first microtron. We discuss to replace at least the injector supply by a modern device since operation at increased energies requires high power operation close to (or even exceeding) the maximum ratings. The other 7 klystrons are connected to an 8-port high voltage supply based on an oil cooled transformer. The unused port is foreseen as backup, if one of the other 100kW devices drops out for a longer period of time. The HDSM is provided with two 900kW supplies. Both are identical in construction and of modular design (the 30kV are generated by a stack of 800V modules) and so we are quite confident to be able to repair these devices in case of falling out. The klystrons themselves seem to exceed their specified average lifetime. Presently less than one device per year must be exchanged on average while 19 are necessary for full operation, but this might take a turn for worse. In order to prevent a critical situation due to long delivery time or cease of production by the manufacturer we hold at least 3 units of both frequencies needed for MAMI-C (2.45 and 4.9 GHz) as spares.

During the energy upgrading efforts the power of the injection linac klystron and the maximum current of the power supply of the RTM3-dipoles turned out as the main obstacles when moving further beyond design energy. Thus, one option for upgrading MAMI is to buy a klystron with slightly more power and to improve or replace this magnet power supply.

## COOLING WATER INSTALLATIONS

As it can be seen in Fig. 4 the second most cause of downtime originates from problems in the cooling water installations. These problems have been aggravated in the last years and are currently the most frequent reason for disruptions. In most of these cases holes arise in copper pipes due to cavitation pitting (Fig. 5). The spraying water in many cases damages electronics or impairs the RF-installations which may cause a failure of the facility for several hours as a result. For this reason we started to review the water flow in all systems for the potential to reduce it without violating the cooling demands. Additionally, if possible, we replace the copper pipes at critical areas by elastomer pipes. The very low radiation background due to the high beam quality allows to use this more flexible and reliable tubing.

Inside water cooled magnet coils we found no evidence of the beginning of such leakages up to now. We suppose, we owe this to one of our basic principles in the construction specifications: to ban pipe joints inside the coil. All water connections to the different layers of a coil are installed outside the coil.

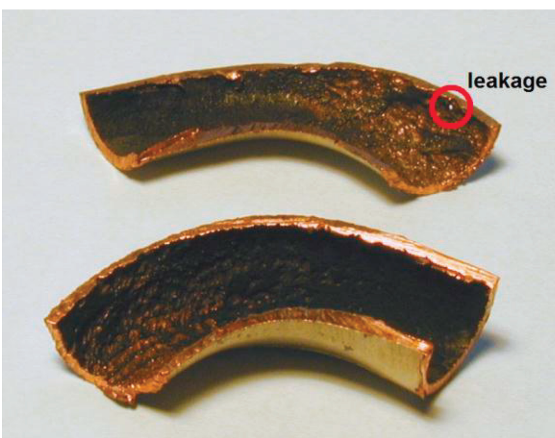


Fig.5: Water pipe with cavitation pits.

## MAGNET COILS

Up to now in general magnet coils seem to have no ageing failures, but we have a defect of the field correction coil in one of the main magnets of the 2nd microtron. These correction coils are plates in size of the pole shoe of a microtron magnet provided with current paths to homogenise the magnetic field to about $10^{-4}$. For each magnet such a plate for both the upper and the lower pole shoe are installed. In the case of the 2nd microtron the plates were constructed using common techniques of manufacturing printed circuit boards. Now the circuit seems to be broken at one location. To access and repair it, a considerable part of the microtron and the magnet must be disassembled implying a downtime of more than 2 months. Fortunately some of the current paths are accessible from outside of the magnet gap and it therefore was possible to reactivate about one third of the coil. By additionally changing the current distribution between both microtron dipoles, the asymmetry could be compensated sufficiently to bring the beam through the microtron stage again without any impact on the beam quality. Problems may arise in case of further energy upgrades, but an emergency plan has been prepared proposing additional steerer magnets on the microtron linac axis to compensate for the expected beam position deviations.

## MAMI CONTROL SYSTEM

Even though the basic ideas of the control system originate from the 1970's, it has been updated and enhanced with the extension of the MAMI facility. A network of control computers was provided in the very first design, though this was not common at that time. It enabled an easy expansion of the system. The rather early move from Fortran as programming language to C was also a benefit. All developments have been done to a large extent in an OS-independent way. By now the control system runs resp. ran under several different operating systems such as RTE (HP), VMS (Digital Equipment), OS-9 (Microware), different Unix-flavours and Windows (MS), demonstrating a quite platform independent implementation [9]. To maintain the system for future operation also the hardware has been updated from time to time. So the control system is still in excellent condition and there is no doubt that it can be kept alive at least for the next decade.

## OPERATION AND FUTURE PLANS

Several nuclear physics experiments are scheduled for the MAMI facility in the scope of the new CRC, e.g. electron scattering input for more exact determination of the anomalous magnetic moment of the muon and the electromagnetic fine structure constant, precise measurement of the Weinberg angle, dark matter search, etc. For some applications accelerator upgrade projects have been launched to go to both higher (above 1.6 GeV) and lower energies (between 80 and 160 MeV). This seems to be possible with rather modest efforts. However, the most important task is to ensure the high reliability of the facility also in the future.

## REFERENCES

[1] K.-H. Kaiser et al.; NIM A593(2008)159, doi:10.1016/j.nima.2008.05.018
[2] P. Achenbach et al.; IEEE Trans. Nucl. Sci. 56(2009)316
[3] J.C. McGeorge, et al.; EPJ A (2008), doi:10.1140/epja/i2007-10606-0
[4] S. Baunack et al.; Physical Review Letters 102:151803, 2009, arXiv:0903.2733
[5] K. Aulenbacher; EPJ Special Topics 198, 361-380 (2011)
[6] R. Heine et al.; "Recent Status of the MAMI-C Accelerator and First Experiences with the Energy Upgrade towards 1.6 GeV"; IPAC 2010, Kyoto, Japan
[7] M. Seidl et al.; EPAC 2000, Wien, p. 1930
[8] M. Dehn et al.; "Various Improvements to Operate the 1.5GeV HDSM at MAMI"; IPAC 2010, Kyoto, Japan, MOPD095
[9] H.-J. Kreidel, M. Dehn; ICALEPCS 2007, Knoxville, Tennessee, WPPA07