

THE FIRST TWO YEARS OF OPERATION OF THE 1.5 GeV CW ELECTRON ACCELERATOR MAMI C[#]

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Abstract

In December 2006 the maximum energy of the cw race-track microtron cascade MAMI B was increased to 1.5 GeV by successful commissioning of the world wide first Harmonic-Double-Sided-Microtron (HDSM, [1]) as a fourth stage. Since then MAMI C was in operation for more than 15000 hours, delivering approx. 10000 hours the maximum beam energy. We report about our operational experiences and recent machine developments, concerning e.g. an energy increase and a stabilisation of the output energy down to 10^{-6} . Topics of machine reliability and stability are addressed and the operation under different demands of nuclear physics experiments is described.

INTRODUCTION

Since mid of the 1970's IKPH was one of the protagonists in the course of developing cw electron accelerators. The chosen machine type was the racetrack microtron (RTM, [2]) with a normal conducting linac. This scheme makes efficient use of rf-power and its inherent strong phase focussing guarantees excellent beam quality and stability. The three-RTM cascade MAMI B delivered since 1990 a low emittance beam of up to 883 MeV and 100 μ A for nuclear and particle physics as well as for proof of principle x-ray generation experiments [3]. With its extraordinary operational stability it satisfied beam time demands of up to 7000 h per year and 6000 h average. For the energy upgrade of MAMI to 1.5 GeV by a fourth stage it was therefore decided to stay with the successful microtron principle. However, because magnet weights for constant magnetic field strength scale $\sim E^3$, the 180°-bending magnets of an RTM would have weighed 2200 to each. Therefore the new stage was realised as an Harmonic Double Sided Microtron [1], which for the same total magnet weight can deliver roughly twice the energy as an RTM. The setup of the four stage MAMI C facility is shown in Fig. 1. With beam currents up to 100 μ A from a thermionic and 40 μ A from an 85%-polarised laser photocathode source [4] the accelerator can deliver energies between 180 and 883 MeV from the RTM-cascade and up to 1558 MeV by the HDSM.

OPERATION HISTORY

From 1991 to 1998 MAMI B delivered on the average a beam time of 5295 h per year, with 79 % on target and 21 % for accelerator improvement and tuning. A detailed 10 years operation history of MAMI within the frame-

work of the 1999 newly founded Collaborative Research Centre (CRC443 "Many-body structure of strongly interacting systems") is shown in Fig. 2. The average annual beam time was 6245 h, with 84 % beam on target. The only 4297 h in 2001 result from a 6 months shutdown needed to prepare all beam transfer lines for 1.5 GeV-operation. The four experimental areas (Fig. 1) have rather different beam parameter demands: the "Spectrometer-Hall" (A1-collaboration) requires currents of some ten μ A in a quite broad range of energies, the "Tagger-Facility" (A2-coll.) can only handle beam currents of max. 100 nA, preferably with the highest energy, and the "X-Ray-Facility" (X1-coll.) needs for its micrometer foci the lowest possible emittance, around 400 MeV from RTM3. The "Parity-Violation-Experiment" (A4-coll.) measures 10^{-6} cross section differences for elastic scattering of longitudinal polarised electrons of a 20 μ A beam, and obviously demands an extreme stability of all beam parameters (e.g. energy to some 10^{-6}). The percentage of beam time with polarised electrons has steadily grown from 25% in 1999 to a maximum of 68% in 2005. The inclusion of the HDSM did not pose any problems to these operation modes: of the 14137 h of beam time in 2007/8, 7467 h (53%) were delivered with the HDSM, mainly at 1508 MeV.

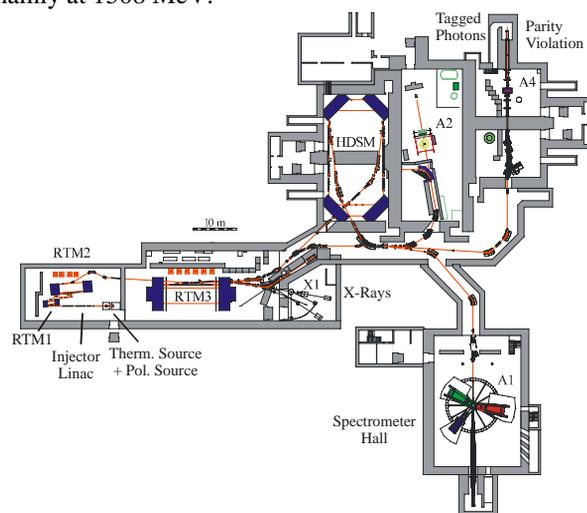


Figure 1: Floorplan of MAMI C.

In its standard operation cycle MAMI is running non-stop from Tuesday, 7am for two weeks till Monday, 6am, operated by four professionals and, during night and on weekend, by trained students, supervised by one specialist on-call duty. The accelerator setup needs ca. 2 h, mainly

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waiting for the eddy-current decay in the big iron magnets of RTM3 and HDSM to less than 10^{-5} . A continuous operation without any operator intervention for more than 24 h is standard, the record is 76 h.

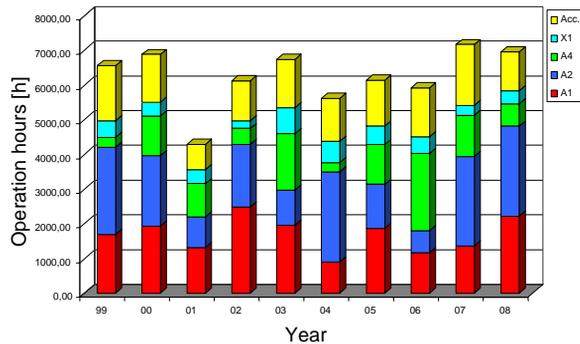


Figure 2: Operation history of MAMI C for 10 years of the CRC443. Acc. comprises: machine development, setup and tuning, as well as failures.

FAILURE STATISTICS

A classification of the 611 h (4.3%) of beam time lost in 2007/8 by accelerator failures is given in Fig. 3. The leading category are the rf-systems. The main failures were small defects at their lots of complicated regulation electronics, but also malfunctionings (destructive arcing, intra cavity multipactor oscillations, cooling water leaks) at one of the 19 klystrons (2.45 GHz: 9 at the RTM's + 5 at the HDSM / 4.90 GHz: 5 at the HDSM). Because of their high cost (~90 k€) these tubes are of course operated beyond their good shape till definite end. The average operating time of the present klystron pool at the RTM's is 49000 h, with several specimens beyond 80000 h. The final drop-out was always caused not by exhaustion of the cathode, but by a vacuum leak, by spread of more and more multipactor-zones on their transfer curves or by permanent gun arcing, withstanding any high-potting treatment. The main measure for a long tube life was to operate the heater nearest to the edge of the roll-off curve. The high voltage (25 kV) power supplies are now in operation up to 25 years without fundamental failures. The accelerating structures did not cause any problems, because of their high quality manufacturing (several sections are in operation for more than 25 years) and as a pay-off of their modest operating conditions (acc. gradient ~ 1 MV/m with 12 kW/m dissipated power). After a vacuum venting they can be restarted without any reconditioning. At the RTM3 the sections tuning plungers had to be replaced after 18 years of operation because of wear of their rf-contact fingers.

The 77 h noted for cooling water problems are only related to direct problems with this system, e.g. repair of pumps and water meters as well as tuning the cooling-tower of the HDSM circuits, which with its design capacity was at the limit to conduct the 1.4 MW of heat load.

In addition, however, quite a part of the rf-system and magnet failures were by water leaks, often caused by ero-

sion corrosion at curved, small diameter (< 12 mm) copper

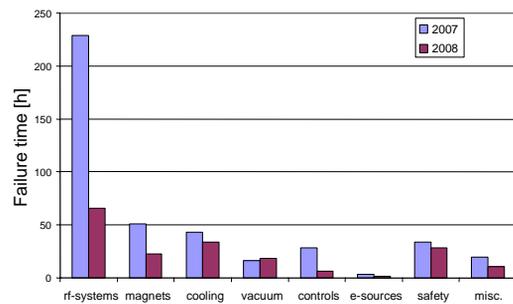


Figure 3: MAMI C failure statistics.

pipes/fittings. As a countermeasure at the linac sections they were successively replaced by stainless steel tubes or by at least straight parts. Wherever possible it was taken care, that the flow velocity stays distinctly below 3 m/s. Moreover, the water specific resistance is carefully controlled to stay above $3 \text{ M}\Omega\text{-cm}$ and the permeation of oxygen to the system is minimised [5]. The magnet failures were, apart from these water leakages, completely due to fatigue of components in their power supplies, especially of electrolytic filter capacitors and power transistors. The repair time at the vacuum system was due to exchange of pumps, esp. of exhausted and arcing ion getter pumps. Concerning the rubric "radiation protection and safety", it must be stated that the security itself was never in doubt, but that beam operation was blocked by a failure of one of the countless hardware components. The control system suffered from some of its computers and interface systems getting into old age. Concerning the nearly zero failure rate of the electron sources it is clear, that only an intense care of the polarised source during the machine maintenance periods can give this result. Altogether it should be emphasised, that a clear majority of all these failures did not occur at the HDSM, but at the aging injector RTM-cascade, now between 18 and 30 years in operation.

CONSOLIDATION

In spite of the stable and reliable operation of the HDSM, detail improvements are steadily going on at the maintenance days (e.g. EMC hardening of subunits, refinement of monitoring and automatic steering routines). As a first larger improvement the variable energy extraction from turn 1 – 30 (0.872 – 1.322 GeV) was finished and successfully set into operation. A beam extraction from turns 31 – 42 (1.337 – 1.495 GeV) would need a modification of the corrector magnet setup in these paths, i.e. a machine shutdown of some weeks. Therefore the demand of the experiments for these energies remains to be seen. A detailed investigation of the transverse and longitudinal HDSM-emittance as a function of beam energy and current, amongst others by analysing the fan of synchrotron radiation beam spots in one of the 90° -dipoles, is under way in a diploma work [6].

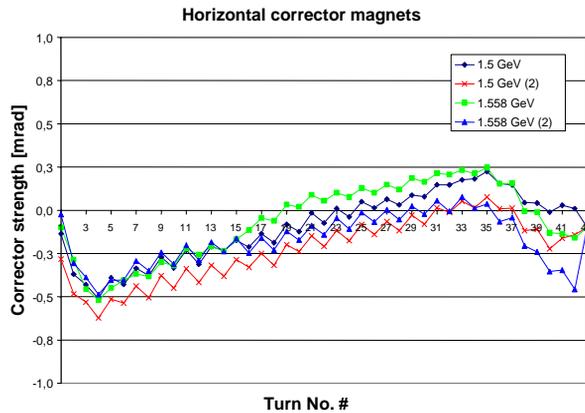


Figure 4: Comparison of the excitations of the horizontal 43-corrector array (at the dispersive section following the 2.45 GHz-linac) for two 1508 and two 1558 MeV setups.

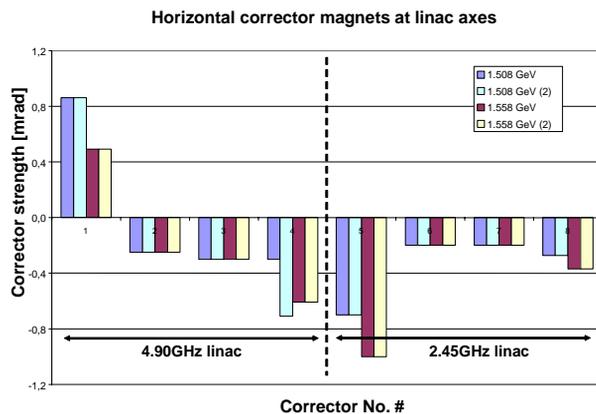


Figure 5: Comparison of the horizontal linac-axes corrector excitations for the same setups as in Fig. 4.

The main projects for the remaining CRC443-period up to 2010 are, however, the determination of the absolute HDSM beam energy to 10^{-4} (150 keV), the stabilisation of this beam energy to some 10^{-6} and an energy upgrade to 1.6 GeV and above. At RTM3 the first two tasks were successfully done, using the transverse and longitudinal dispersion of one of the 180° -dipoles with its 10^{-4} homogenous field distribution [7,8]. At the HDSM the beam optics is distinctly more complicated, because of the field profile in the 90° -dipoles (1.54 T – 0.94 T) and because the extraction path includes two additional small angle bending magnets. For the absolute beam energy measurement TOSCA and PTRACE simulations and detailed error estimations are still under way. The setup for energy stabilisation at 1508 MeV is installed, a 4.90 GHz TM_{010} -phase-cavity plus a TM_{110} -position-cavity on the 43th return path as well as on the extraction beam line. The method is adapted from RTM3: a sensitive time of flight difference measurement by phase comparison of the two TM_{010} -cavities, and correction of errors due to angular beam deviations by the position resonators upstream and downstream of the 90° -dipole. Because of the only 90° -deflection and the higher synchronous energy gain of 13.9 MeV in the last turn of the HDSM (7.5 MeV / turn in

RTM3) the phase sensitivity ($-0.013^\circ/\text{keV}@4.90\text{ GHz}$) is only a fourth of the RTM3-value, whereas the influence of angular perturbations is roughly the same ($0.03^\circ/\mu\text{rad}$). The system is currently under commissioning.

The 1508 MeV end energy of the HDSM resulted from two conditions: first the machine had to be built into an existing hall and second a moderate value (1.54 T) was chosen for the maximum field strength of the 90° -dipoles. For this field level the field correction coils were built [9]. However, because of the foreseeable experimental demand also field maps at 1.64 T and 1.71 T were taken, corresponding to maximum energies of 1.61 GeV and 1.68 GeV. At these fields the magnets show, as expected, distinct saturation effects, mainly at their right and left edges.

Investigations concerning other possible hardware limitations were undertaken and gave the promising evidence of only minor modifications to be necessary for a 1.6 GeV operation, mainly at the interfaces between the RTM's. The 180° -dipole power supply of RTM3 turned out to be capable of delivering the current for raising the field from 1.284 T to 1.362 T, corresponding to the necessary 907 MeV HDSM injection energy. In a first attempt an intermediate step towards higher energy was taken: based on existing 883 MeV setups of the RTM-cascade (the by now maximum operation energy) and by a 1.033 (=883/855) scaled HDSM the extraction energy of 1558 MeV was achieved straightforward in December 2008. A comparison of the excitations of the return path corrector magnet arrays for 1508 MeV and 1558 MeV shows no strong deviation (Fig. 4) after carefully adjusting the linac-axes correctors (Fig. 5). As all correctors are well below ($< 25\%$) their max. possible values, we are confident that at 1.64 T the change of the field distribution in the 90° -dipoles will be small enough to stay within the range of the corrector magnets. To perform this test, a consecutive tuning of the RTM-cascade towards 907 MeV extraction energy will be done.

To achieve a 1.71 T / 1.68 GeV operation of MAMI C will be distinctly more difficult. In addition to the growing saturation effects at the HDSM magnets, RTM3 must be tuned to 950 MeV (1.42 T). Then also the field of its 180° -dipoles may show deviations from their 10^{-4} homogeneity and one must also invest in a new power supply. Moreover, because the necessary rf-power grows with the square of the energy, the klystrons will get to their limit, allowing only a beam load of a few μA .

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