RECENT STATUS OF THE MAMI-C ACCELERATOR AND FIRST EXPERIENCES WITH THE ENERGY UPGRADE TOWARDS 1.6 GEV*

R. Heine, K. Aulenbacher, O. Chubarov[#], M. Dehn, H. Euteneuer, A. Jankowiak[†], P. Jennewein,
H.-J. Kreidel, U. Ludwig-Mertin, P. Ott, G. Stephan, V. Tioukine
Institut für Kernphysik (IKPH), Universität Mainz, Germany

Abstract

The University of Mainz' institute for nuclear physics is operating the microtron cascade MAMI (Mainzer Mikrotron) since the late 1970ies. The microtron delivers a cw electron beam to users of the hadron physics community. The recent, fourth stage MAMI-C having a design energy of 1.5 GeV is operated since 2006 [1].

This article deals with the recent developments and operational experiences of MAMI-C, as well as with the energy upgrades to 1.56 GeV [2] and as final step towards 1.6 GeV. The final increase of beam energy was due to user demands, since it is expected to raise the event rate of the η'- production by an order of magnitude.

INTRODUCTION

The MAMI microtron cascade consists of four microtron stages, three racetrack microtrons (RTM, [3]) set into operation between 1979 and 1990 and a harmonic double sided microtron (HDSM, [4]) commissioned in 2006, all of them using normal conducting rf-technology. A normal conducting 3.5 MeV linac is used as injector.

The setup of the four stages MAMI-C facility is shown in figure 1. With beam currents up to 100 µA from a thermionic and 40 µA from an 85%-spin-polarised laser photo cathode source [5], the accelerator can deliver energies between 180 and 910 MeV from the RTM-cascade and up to 1604 MeV by the HDSM.

The RTM-scheme was chosen because of its efficient use of rf-power and its inherent strong phase focussing, which guarantees excellent beam quality and stability. Since the RTM's magnet volume scales with the third power of the particle energy, this microtron type was no more feasible and the never before built HDSM-scheme had to be utilised. A HDSM reaches for the same total magnet weight twice the energy of an RTM.

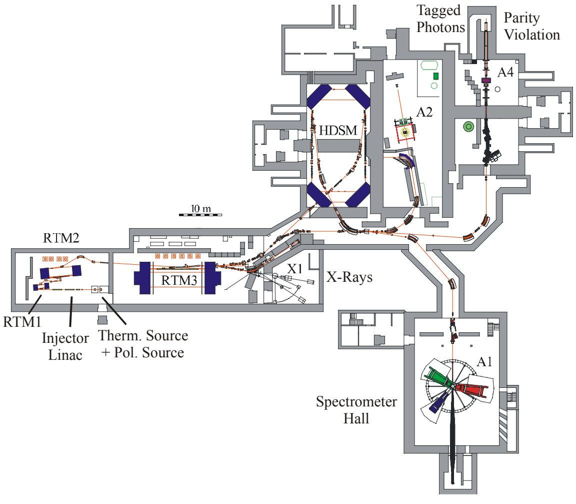

Figure 1: Floor plan of MAMI-C.

OPERATIONAL EXPERIENCES

The MAMI microtron cascade delivered an average beam time of 6189 h per year throughout the last decade, with roughly 85% beam availability to the experiments (see figure 2). The remaining time is owed to setting up and optimizing the machine. MAMI is usually operated in a two weeks cycle, starting Tuesday at 7 am and ending Monday at 6am, followed by 24 h of maintenance shut down.

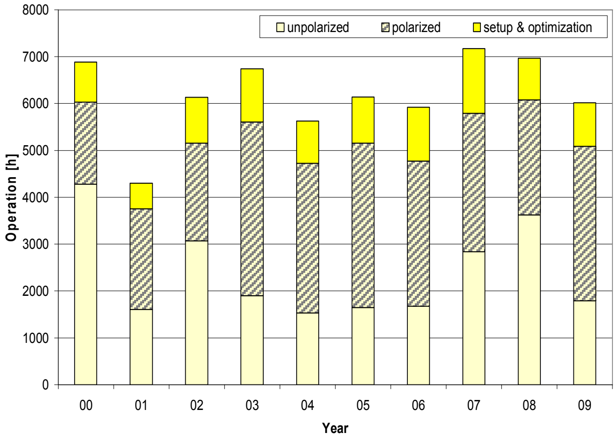

Figure 2: Operational time overview of the last ten years, classified into polarised or unpolarised operations and time for setup and optimization.

Since 2007 the HDSM is in routine operations, with a continuously increasing portion of beam time being now 72%. Currents up to 40 µA were accepted by the experiments.

The majority of user beam time was conducted with spin-polarised beam, which is (since 2008) generated from a GaAs/GaAsP superlattice photocathode [6]. Hydrogen pre-cleaning of the cathodes has proved to yield good quantum efficiency with high reproducibility [5].

Beam downtime due to machine failure was at 3.6% of the overall beam time in 2009. The main sources of failure were again rf-systems, magnet power supplies and cooling issues (see figure 3). While those malfunctions decreased in the HDSM because of further consolidation of the newly built systems, they increased in the old mi-

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#) New affiliation: Siemens Medical Solutions, Erlangen

†) New affiliation: Helmholtz-Zentrum Berlin, Berlin

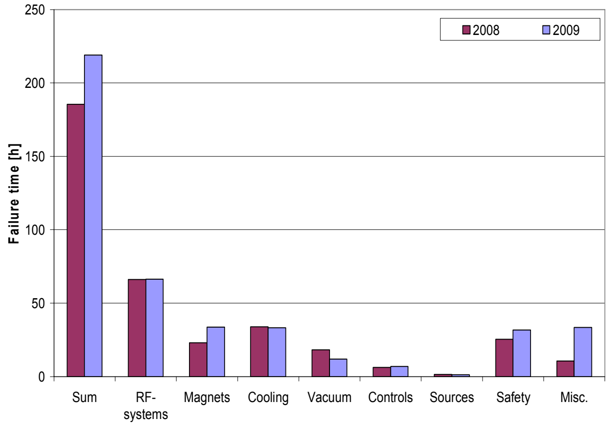

Figure 3: Failure statistics of 2009 compared to 2008 itemised by accelerator subsystems.

crotrons as a matter of aging of components. Mainly capacitor and transistor failures were the cause for down time. As a precaution those parts were exchanged during maintenance periods in all existing elements, where a similar fault appeared repeatedly.

The HDSM extraction energy stabilisation system has been successfully commissioned for maximum energy [7] and is now in routine operation for special experiments. The stabilisation system consists of two rf-cavities for phase measurement, and one main dipole forming a time-of-flight spectrometer. The first cavity is located before the dipole on the last return path and the second is placed in the extraction beam line. The time of flight is regulated by shifting the phases of both the 2.45 GHz and the 4.9 GHz rf-system by a corresponding amount.

ENERGY UPGRADE

The dipole magnets of each microtron are made of cast-iron. To achieve field homogeneity of 10^{-4} field correcting plates are inserted into their gaps adding a certain current distribution to the field correcting its errors [8, 9]. The HDSM-magnets also incorporate a field gradient compensating the defocusing due to the particle trajectories tilted crossing of the magnet's front face. Since the correcting plates are optimised for the design field of 1.54 T, the field quality near the pole edges, where the beam enters and exits the HDSM's 180° bending systems, degrades strongly for fields above design [2], e.g. the difference between the edge field and the reference field grows by more than an order of magnitude for 1.64 T, the field necessary to accelerate to 1.6 GeV. It was intended to match this lack of field resulting in an orbit displacement with the HDSM steerer magnets. In a first step an intermediate energy upgrade step based on an existing 883 MeV RTM-setting was successfully taken in 2008 [2].

This was encouraging to aim towards 1.6 GeV, but was in turn demanding, because it required a complete new machine setting, pushing all accelerating stages into absolutely unknown operating ranges.

As the facility was now intended to be operated 6% above design values, it had to be investigated whether there were limiting components. So the theoretical value of each component at 1.6 GeV was compared with specifications. Only two components were regarded as critical. The first one was a bending magnet of the transfer system between RTM 1 and RTM 2 (see figure 1), whose theoretical setting was slightly above its specified maximum. A backup power supply was installed, but not needed since a modification of the injection path decreased the demand on this particular magnet. But second, also the RTM 3 main magnets' power supply was close to its nominal value. Thorough investigations were undertaken to ensure that the power supply's regulation margin was still large enough to cover field drifts due to temperature changes.

The main and reverse fields of all RTM dipole magnets were carefully adjusted by using field probes, because saturation effects were expected. The magnets were also power cycled several times until the current values became stable. In the course of this, the RTM 2 field corrector power supplies were replaced by remote controllable species to establish a more comfortable setup procedure for different beam energies.

The energy of the injector linac was raised from 3.5 MeV to 3.7 MeV, but keeping the energy gain in the first accelerating section untouched since it is a graded beta structure.

The HDSM lattice contains more focussing elements than the RTM, so an application to scale all quadrupoles of a kind at a time was implemented to correct the working point more easily.

With these preparations the beam test was soon a success. On a first attempt the beam was accelerated into the second stage. There it turned out that although the beam could be accelerated through the RTM 2, injection was not perfect. This problem was easily solved by adding a new corrector magnet in the injection path. Further acceleration through the microtron cascade then was straightforward, although it took a bit more flair to find the right machine settings than experienced with the intermediate step. So 1.6 GeV was reached within an overall time of 24

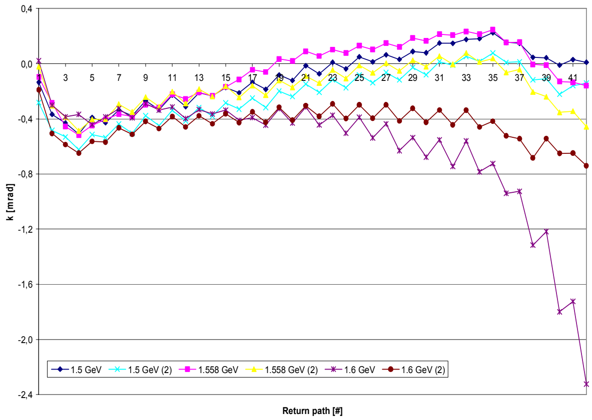

Figure 4: Distribution of steerer strength k relative to recirculation number of the first horizontal steerer in the return path between the 90° bending magnets following the 4.9 GHz linac for two settings at different HDSM energies.

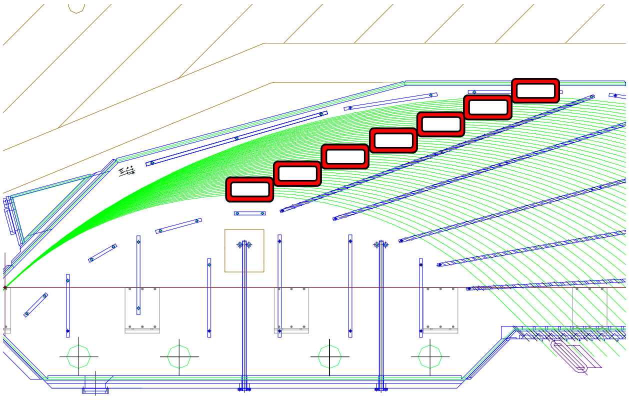

Figure 5: Position of the in-gap steering coils (red rectangles) inside a HDSM dipole. The green curves mark the particle paths.

working hours. During these beam tests the machine was shutdown over night due to manpower reasons, but the setup was absolutely reproducible.

Investigations on the HDSM concerning steerer strengths showed the expected strong excitation of the elements of the return paths at higher energy being close to or above their limit of 2 mrad (figure 4). This excitation could be reduced by the use of the in-gap steering coils [10], which were foreseen for this purpose in the HDSM dipole design, but never used before.

Each dipole incorporates seven additional steering coil pairs acting on six return paths each. The coils are placed near the angular point of the corresponding arcs inside the magnet and produce an orbit displacement at the exit of the magnet (see figure 5). Depending on the combined use of these coils around the HDSM not only orbit shifts, but also a longitudinal phase displacement can be established. In figure 4 it shows the effect of the in-gap steering coils on the steerer strength k. The curve labelled “1.6 GeV(2)” demonstrates the behaviour with the in-gap steerers being active. The loading of the return path steerers now is in the range of normal 1.5 GeV operations.

At 1.6 GeV a beam current of 20 µA (30 µA at 1.56 GeV) was achieved at tolerable radiation level. From the point of rf-power it is possible to go beyond those figures, if careful machine tuning is able to diminish the radiation level.

Going to 1.7 GeV is not possible unless noteworthy investments and a long term shutdown are applied, since the RTM 3 main field power supply needs an upgrade as well as the HDSM 4.9 GHz rf-system. The HDSM dipole field corrector plates will likely have to be reconstructed to fit to the higher field

MISCELLANEOUS

In course of a diploma thesis an emittance monitor for the HDSM was set into operation. This monitor uses the synchrotron radiation fans emitted in one of the 90° bending magnets by the beam in each turn. The light is detected by a networking CCD-camera. The area illuminated on the chip depends on the beam emittance and the beta function at the source point. The beta function was measured by successively putting a movable quadrupole on the return paths and then varying beam position and quadrupole strength, while measuring the effect on the beam. Further, effects that lead to a virtual emittance broadening were taken into account. The measurements support the simulations of emittance growth in the HDSM which predict a doubling of normalized emittance in the HDSM [4]. Compared to RTM 3, this results in a similar geometrical emittance since the HDSM approximately doubles the energy. [11].

The HDSM absolute beam energy measurement turned out to be more delicate than expected. Sound considerations, simulations and error estimations resulted that adopting the RTM 3 measurement scheme to the HDSM, with a main bending magnet being used as a spectrometer and the beam position monitors determining the energy dependent deflection, as well as using the HDSM energy stabilisation setup with absolute phase measurement, would not result in the desired 10^{-4} accuracy. The main problem in both cases is a proper calibration of the system. To overcome this limitation, it is now intended to establish a separate spectrometer in the beam line to the experiments (figure 1), where it can be calibrated with the well-known beam energy of the RTM 3 [12].

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