Experience with the 855 MeV RTM-Cascade MAMI*

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Abstract

A report on the main experiences with the Race Track Microtron cascade MAMI through 18 months of operation is given.

1 INTRODUCTION

The 855 MeV cw-electron-accelerator MAMI (MAinz MIkrotron) is working since 18 months for intermediate energy nuclear physics coincidence experiments, after a smaller 180 MeV-version sucessfully operated for photonuclear work 1983 - 87. The machine consists of a 3.5 MeV injector linac and three cascaded RTM's for 14, 180 and 855 MeV respectively. An overwiev of the basic operational principles and the design of MAMI can be found in [1] and, in a more general context, in another paper of this conference [2]. Here we give a report on our main experiences with this rather complicated machine.

2 SETUP AND BEHAVIOUR OF MAIN SUBSYSTEMS

2.1 Injector and RTM1

The replacement of the 2.1 MeV van de Graaff injector by a 3.46 MeV rf-linac, then omitting the first two turns of the old RTM1 setup, was one of the most valuable changes for increased stability and reliability of MAMI. A slight adjustment of the rf-amplitude in the booster-section (accelerating from 1.99 to 3.46 MeV) is the main fine correction for beam matching from linac to RTM1.

A 100 keV-beam of polarized electrons, coming from a lab 20 m distant from the machine hall was sucessfully guided into and through MAMI to the target setup. Because the lifetime of the polarized source is strongly influenced by the current drawn, it was tested how far the phase acceptance of the linac reaches beyond the 36° normally cut by the chopper setup. It turned out that with till now not too sophisticated readjustments at the prebuncher and the first two sections of the linac, up to 120° of the gun beam can be guided through MAMI with deteriorated but acceptable phase volume.

In the rebuilt RTM1 all components were improved or exchanged: e.g. more diagnostics was put into the vacuum chambers, the new accelerating structure has parallel coupling slot pairs, i.e. a compensated rf-quadrupole [1] and for focusing the solenoids with their awkward stray field were replaced by quadrupole singletts.

The system linac + RTM1 shows excellent stability: the 14 MeV-beam is reproduced by computer setup with nearly no changes from run to run and cw-currents up to 210 μA were stably accelerated.

2.2 RTM2

The changes in the setup of RTM2 were less extensive. Only the coils of the 180°-magnets were replaced by new ones with a more efficient cooling and more sophisticated [2] surface correcting coils for field homogenization were manufactured. The rf-sections were reused after careful inspection, however, because their resultant rf-quadrupole could not anymore be compensated, they were tilted around the beam axis such that this weak quadrupole is no more a skew one.

Concerning the focusing in this machine with a quadrupole duplett at each end of the linac, it was realized that the old arrangement of the four quadrupoles is not optimal. It was mirror symmetric (+ −/− +; +$\widehat{=}$ horizontally focusing) and new calculations showed, that the antisymmetric scheme + −/+ − allows an easier injection matching as well as, because the initial focusing can be 10 % stronger, lower β-functions at the RTM output. Therefore this scheme was adopted for RTM2 and RTM3. The beam is extracted out of RTM2 only at full energy. For longitudinal matching to RTM3 a schicane beam bump is inserted in the last return path (it shifts the bunches from -16° to a phase angle of -23° for one linac passage) and furthermore a short rf-section behind RTM2 allows a fine adjustment of the energy by ±340 keV. The principal performance of RTM2 is excellent up to 110 μA, very often the beam is accelerated to 180 MeV directly after computer setup. However, there were quite strong long time drifts of the beam position and moreover a transverse moving of the beam spot by ±1 mm with a frequency of some hertz. The first effect has been observed to a weaker extent already in the old setup and was attributed to a warm up of the 180°-dipoles by insufficiently cooled coils. It turned out however, that it was caused by different thermal expansion of two steel rods carrying a movable mounting stage and resting on the two dipoles. Calculations showed that a relative tilt of these two magnets by only 0.01 mrad in the horizontal plane results in a beam movement of 2.6 mm (for RTM1 and RTM3 the respective numbers are 0.4 and 1.4 mm). Also the beam spot moving could be assigned to horizontal rotary oscillations of the magnets. With their new and apparently too weak support structure – the beam height over ground had to be raised from 1.1 m to 1.8 m in

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the new setup – they showed a resonance at about 6 Hz, which was excited by microseismic movements of the building. An effect on the beam by heavy construction machinery several 100 meters away was clearly observable. After reinforcing the support to the ground by 30 mm thick steel plates on the two sides of each dipole, which was calculated to shift the resonance to about 100 Hz, the beam moving has essentially vanished.

2.3 *RTM3*

The operation of RTM3 turned out to be unexpectedly uncritical, mainly due to the very careful homogenization of the 180°-magnets to $2 \cdot 10^{-4}$ and the rather low ratio of 4.75 of output to input energy. An example of the correction angles by the four steerers on each return path to direct the beam through the RTM's is given in Fig. 1; one can see the smooth guiding through RTM3.

The operation of the 450 to-magnets is such, that they are switched on with a ramp of 12 min and are switched off instantaneously (naturally with diodes across the coils). After switch on one has to wait 1.5 h for the dieing away of eddy currents. Because the vacuum chambers extend through the fringe field, during the quick switch off electromotive forces of about 15 tons are tearing apart them; in the early days of the machine an insufficient mechanical blocking of this effect caused a vacuum leak. No microseismic shaking of these magnets is observed; small movements of the beam over serveral days are assigned to deformations of the quite new building.

The accelerating structures of RTM3 were built such, that the second half of each section is identical to the first, but rotated by 90°. Therefore their rf-quadrupole is compensated on the average and no tilt of the sections is necessary.

2.4 *RF-system*

The eleven high power accelerating sections of MAMI [3] worked without any difficulties. After an opening up of the vacuum system and the time for repumping (about 12 hours at RTM3) they accept their nominal power (7 – 14 kW/m) within less than one hour. In RTM3 the beam can be accelerated by only four instead of five sections with an owerpower of 56 % in them. Astonishingly the operation of two low power (≤ 2 kW/m) sections for longitudinal matching between the microtrons is much more critical; they now and then show short vacuum breakdowns, probably caused by multipacting. – After two years of operation the main parameters of the sections (Q-value, passband-gap, rf-matching) were carefully remeasured and no change was found. This is in good contrast with the old RTM2-setup, where one of the knife flanges [4] connecting the three parts of each section got bad contact and caused a 20 % decrease in Q – but was repairable by just refastening its bolts.

The two tuning plungers in each section reliably stabilize their phases to $\pm 1°$, which is just at the tolerable limit for the injector linac. Their effective tuning range of +150, -350 kHz in the long 35-cell sections of this linac is however sometimes a little too narrow for the currently not very good temperature control of the cooling water system, which unfortunately is partly done by an external cold water supplier.

Some work had to be done on the high voltage power supplies concerning EMC-problems with the crowbars. The rf-interlock system was upgraded such, that the essential trips (e.g. switch off of the klystron high voltage in case of a failure of the focusing solenoid) are done on two independent hardware paths. With the klystrons TH 2075 there is a still unsolved problem: an apparently insufficient match between the tubes and their focusing coils, i.e. it is not sure that every tube works in every coil within the body current limit given by Thomson. The control loops regulating the klystron-amplitudes (± 0.1 % for the RTM's, ± 0.05 % for the injector linac) and -phases ($\pm 0.5°$) via their rf-input worked satisfactory, but their test at high beam loading is still missing. The waveguide rf-distribution system with its many movable shorts caused no problem.

2.5 *Computer steering*

Since the first operation of the new MAMI setup in August 1990, when the beam steering in RTM3 had to be done partly by hand, the computer control [5] has regained its old power and clearly beyond. A workstation giving a detailed graphic display of the status of the machine has been added. With MOPL (Mami Operator Programming Language) the operators can easily generate procedures for repeated complicated operations on the machine. Because many components of MAMI were replaced by "cleaner" ones, the prediction capability of simulation programs (e.g. [6]) has grown very much.

3 GENERAL OPERATING EXPERIENCES

MAMI has been sucessfully operated for 1300 h in the 18 months since the first beam, mainly in the night and on weekends because of ongoing construction work in the halls. 1050 h were for nuclear physics experiments, the rest for beam tests and operator training. The operators were often skilled physics students. Since some months the machine works often more than 10, sometimes more than 40 hours without any correction by the operator. The normal setup-time for MAMI is less than one hour, roughly the same time it takes to guide the beam to the experimental areas, mainly because the computer steering of the transfer system is not completed.

High current tests till now suffered from two facts: first the component-safety system, consisting of ferrite current-monitors and ionization chambers for detection of γ-radiation, was not fully installed because of lack of manpower. Second the beam dumps capable of enduring the full 86 kW of beam power were not available for "γ-activation" because of ongoing construction work in their immediate environs. For some 10 sec a current of 40 μA

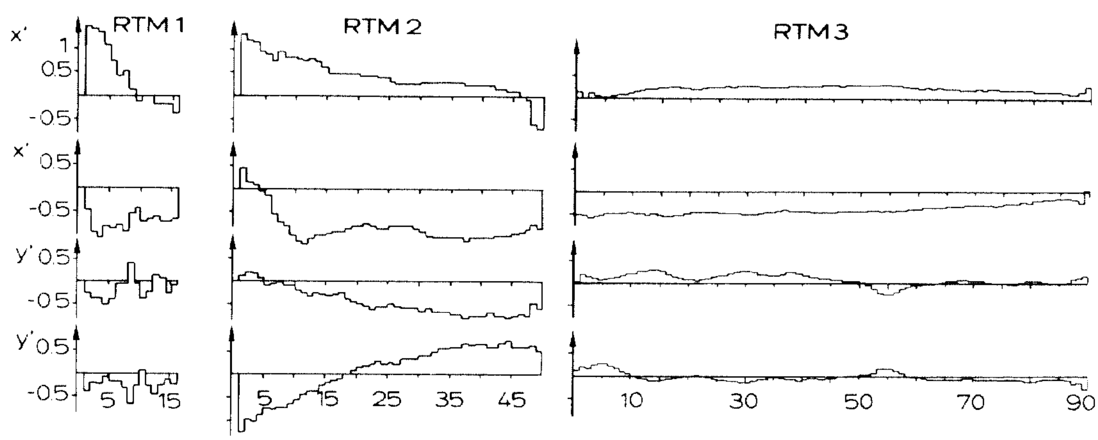

Figure 1: Angular corrections for guiding the beam through the three RTM's (ordinate in mrad).

was accelerated to 855 MeV and dumped in a simple uncooled aluminum block. The highest current with this energy given to the users was 10 μA.

Most of the time MAMI worked at 855 MeV, but also beams of 180 MeV (bypassing RTM3) and higher (by moving the extraction dipole to the appropriate return path) were guided to the experimental areas. A second extraction magnet is ready for installation. For the experimentalists a precision calibration of the beam energy to $1 \cdot 10^{-4}$ is under way; it is done by measuring the beam bending radius in RTM3 to ± 0.1 mm by the rf-position monitors on the linac axis and the mid passage of a precisely aligned quadrupole on the return paths.

A vertical and horizontal emittance of 0.04 π·mm·mrad at 855 MeV and 0.1 μA was estimated by determining the synchrotron radiation spot-size at different places in and behind RTM3. Naturally faint beam halos, e.g. caused by quantum fluctuations of synchrotron radiation [2], are not seen with the simple TV-camera looking at the synchrotron radiation spots. A measure for the transmission of the machine and a possible halo was the intensity of γ-radiation from the narrowest point in RTM3, a collimator with only 13.5 mm aperture in front of its linac: 20 m downstream the radiation was 50 μSv/h at 1 μA and proportional to the current; this same level was produced by stopping a current of 1 nA in the linac. Because the resolution of the experiments served by MAMI till now was only 0.5 MeV, the energy width of the beam is not exactly known at present.

If in the well tuned machine by a perturbation at the input to one of the RTM's a vertical or horizontal betatron-oscillation is excited, one can see in RTM2 and RTM3 slowly growing oscillations in the respective other plane (Fig. 2). This coupling can be compensated by two 45°-skew-quadrupoles on the linac axis: nearly perfectly in RTM3 (where the 8 cm long quadrupoles with a strength of 38 mT/m were placed at the ends of the linac) and quite good in RTM2 (where because of lack of space one quadrupole was in front of, the other in the middle of the linac). The reason for this effect is still not clear.

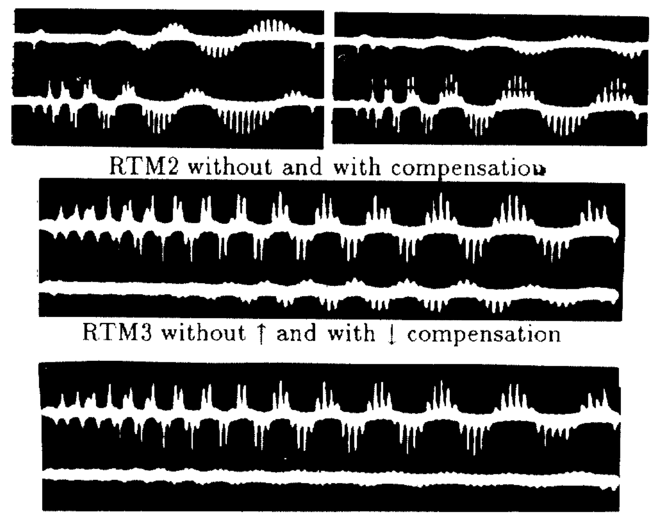

Figure 2: Transverse coupling without and with compensation by 45°-skew-quadrupoles. RTM2: vertical, RTM3: horizontal betatron oscillation excited.

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