FOUR YEARS OF OPERATION OF THE 180 MEV CW ELECTRON ACCELERATOR MAMI A*

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Abstract

At Mainz university a cw electron accelerator, consisting of two cascaded race track microtrons (14 and 180MeV) with a Van de Graaff preaccelerator, have been taken into operation in march 1983. From the beginning the machine was relatively easy to operate and ran stable over many hours with a very good beam quality. The transverse beam emittance turned out to be slightly increased to about 0.014 π mm mrad at 183MeV mainly due to geometrical and chromatic aberrations, whereas the measured energy spread of about 30keV FWHM corresponded to the design value. Most of the technical problems were caused by the Van de Graaff preaccelerator and by its sensitivity to γ-radiation, which limited the maximum beam current to about 65μA at full energy. In the period from 1983 to 1987 MAMI A has been operated for 18,670 hours altogether and 17,160 hours for experiments in nuclear physics. Only 17% of this time were used for accelerator tuning and for the repair of acute failures([1]).

Short description of MAMI A

The general setup of MAMI A and its functioning is given in [2], details are described in numerous internal reports and diploma works. In Fig.1 the scaled scheme of the accelerator is shown. The 2.1MeV electron bunches supplied by the Van de Graaff preaccelerator are matched to the 14MeV microtron by energy modulation in the first buncher section and flight time compression in the magnet system following it. After a phase shift of totally 38° in the first turns due to the relatively low injection energy the bunches draw to the asymptotic value of -22°. The transverse motion is stabilized by two solenoid lenses on both ends of the accelerator axis. In order to adapt the beam to the 180MeV microtron the bunch length is reduced by the second buncher and the longitudinal dispersion of the second interface system. As the longitudinal motion in the 180MeV stage is more stable the synchronous phase can be put to -16°, leading to a smaller energy spread in the beam. Quadrupol doublets at each end of the accelerator axis serve here for transverse focusing. In spite of the focal strength decreasing with the electron energy the spot size stays nearly constant in both microtrons because of pseudo-damping.

The accelerator and buncher sections are fed by the combined power of two 50kW- klystrons by means of a wave guide system allowing individual phase and amplitude control. Quick rf-amplitude fluctuations, resulting from high voltage ripple and changes in beam loading (which moreover is different for both microtrons) are stabilized by two feedback loops: one controlling the rf-distribution between the two stages by a common phase shifter in the klystron input and the second regulating the central amplitude (by the body-collector voltage of the klystrons [2]. The rf-phase of the accelerator sections is automatically held constant with a precision of better than one degree by means of tuning plungers in them.

Operation

From the beginning MAMI A was easy to operate and ran stable over many hours at beam intensities up to about 30μA. Because of the efficient monitor system which included a)rf-cavities on the accelerator axis of both microtrons for beam intensity, phase and position for each revolution in connection with short diagnostic pulses, b)synchrotron radiation monitors for the beam profile in the second stage, c)wire scanners for beam position and profile and d)ferrite transformers for the beam current in the transport systems, the machine could permanently be controlled and troubleshooting was easy and quick in most cases.

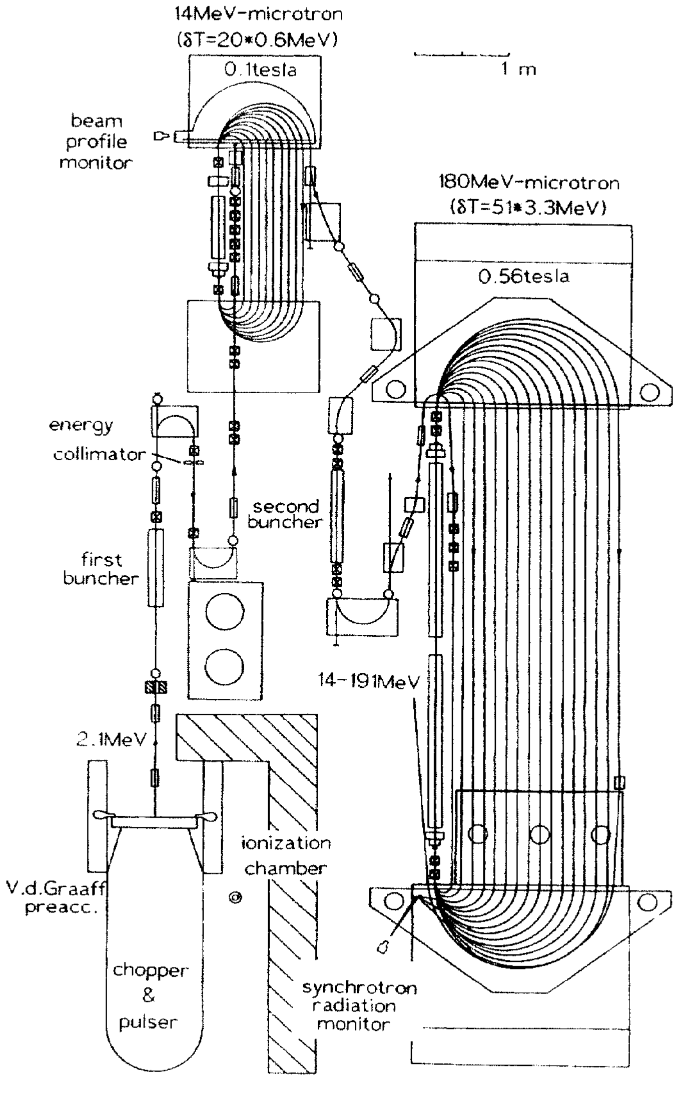

Fig.1: Scaled scheme of MAMI A

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Owing to the extensive computer control system the beam was normally set up in less than one hour. Fine tuning, however, took sometimes one to three more hours depending on the condition of the preaccelerator and on the requirements of the experiment. Numerous turn-on and automatic-control routines as well as beam optimization algorithms on the computer were extremely helpful and made it possible to delegate the control to students on weekends and at night.

Interruptions of the beam time due to machine optimization and acute failures used up only 20% of the total operation time at the beginning, dropping to 14% at the end of the 4 years operation period.

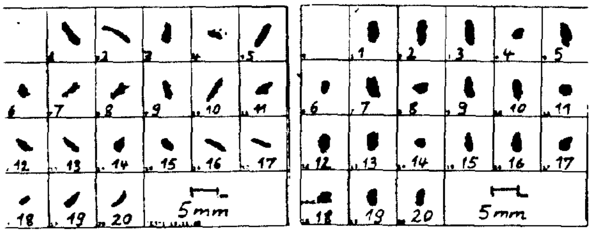

Fig.2: Beam spots in the return paths of the 14 MeV microtron. (left: in case of halo, right: after removal of halo)

Beam Characteristics and Improvements

During the first beam tests with MAMI A a relatively strong coupling between the horizontal and vertical movement in the second microtron associated with a long and tilted beam spot was detected. This effect could be compensated in a pragmatic way by a weak quadrupol on the accelerator axis rotated by 45° with respect to the normal orientation.

By a further improvement of the machine tuning in the following weeks, the diameter of the beam spot in the second microtron was reduced to the design value of about 2mm for intensities up to 30µA. At higher current values a slight increase of the phase space was produced by larger voltage fluctuations of the preaccelerator and, eventually, by higher cathode heating. (Normally, the cathode was only heated to get a maximum beam current of 30µA in order to increase its lifetime).

Measurements of the phase space behind the V.d.Gr. preaccelerator and the detection of the beam spot size at the target indicated sometimes to a total transverse emittance growth of roughly a factor of four to which mismatches and aberrations in the transport system behind MAMI A also seemed to contribute.

A detailed investigation of the beam behavior in the second microtron[3] showed that the emittance of the beam is practically not increased by the acceleration process.

Sometimes , the beam spot had a halo which contained only a very small fraction of the intensity, but which was disturbing for experiments using solid state detectors close to the target. The procedure for the halo removal came out different each time and required a variation of transverse and longitudinal parameters mainly in the first interface. Therefore, a movable screen was installed in the vacuum chamber of one of the 14MeV microtron magnets. It proved that, in case of halo, the spots were irregular and sometimes bizarre because of mismatching and geometrical and chromatic aberrations in the first interface (s.Fig.2). After some slight improvements by the replacement of solenoids and Panofsky-type quadrupoles by conventional quadrupoles it became clear, that the main problem resulted from the small acceptance and from the difficulty to tune the large number of optical elements of this magnet system.

The energy spread and energy stability of the beam were measured several times and with different electron spectrometers. The avarage value of about 30keV FWHM was consistent with the design calculations. Due to the precise flight time measurement by bunch phase monitors in the microtrons with an accuracy of better than $\pm 1 * 10^{-12}$ sec and due to magnet field stabilisation with the aid of NMR probes, the mean energy was stable within ±12keV.

Injection Problems

Beam Chopping

The chopping system in the high voltage terminal of the Van de Graaff preaccelerator consisted of a transverse deflecting cavity driven by an oscillator(disc-seal triode) at one half of the MAMI frequency and a small aperture a few centimeters downstream. For phase locking the oscillator frequency was detected by means of a pick-up cavity directly behind the Van de Graaff and compared with the klystron phase. The error signal was then transmitted by an optical connection back to the high voltage terminal in order to tune the resonance circuit of the chopper oscillator.

Problems were mainly due to the sensitivity of the rf-triode to acoustical noise and to difficulties with electrical contacts in the coaxial circuits. The phase jitter could be reduced to a few degrees by careful shielding and damping of the decharging screen of the V.d.Gr. which turned out to be the main source of noise.

For non professionals the handling of the phase locked loop was difficult because of phase shifts in the rf-circuit with the beam current variation, and because of the fact that the system had to be driven always at maximum loop gain. In order to avoid the chopper being operational at experiments using only low intensity a collimator has been installed in the dispersion region behind the first 180°-magnet(s.Fig.1). Its aperture was chosen to allow the transmission only for electrons in the accepted energy range which resulted simultaneously in beam chopping because of the energy modulation by the buncher. In addition to the very good emittance - the beam spot was reduced to a few tenths of a millimeter in the second stage - the reliability of the machine was significantly improved by this operation mode.

Energy Stability

Due to the relatively low injection energy the longitudina acceptance of the first microtron was rather small, especially in phase, and nearly filled up by the beam emittance. Therefore, the voltage fluctuations of the preaccelerator which gave rise to phase variations at the microtron entrance must be compensated to less than ±0.5kV. For this purpose the rf-phase of the buncher is driven proportional to the reading of the generating voltmeter (GVM of the V.d.Gr. making use of the linearity of the accelerating wave around zero energy gain (s.Fig.4a,b).

Transverse beam vibrations and too large intensity losses at higher voltage fluctuations gave rise to the presumption that the voltage measuring device of the the Van de Graaff did not work correctly Therefore, in order to check the stability of the beam energy after passing through the first buncher, another pick-up cavity was installed behind the second bending magnet of the first interface fo time-of-flight measurements in connection with the cavity in fron of the first magnet (s.Fig.3). Thanks to the good energy resolution of $0.5 * 10^{-4}$ obtained with this arrangement the generating voltmete could be investigated in detail. It turned out that the signal of this device which uses two sets of periodically blinded influence plates is disturbed by mechanical tolerances. Since the set-up could no be improved in a simple and fast way, the ripple was suppressed by a low pass filter, and the signal for the higher frequencies wa taken from two static influence plates of the V.d.Gr. and added t the original signal with the right amplitude after passing a high pass filter of the same time constant (s.Fig.3).

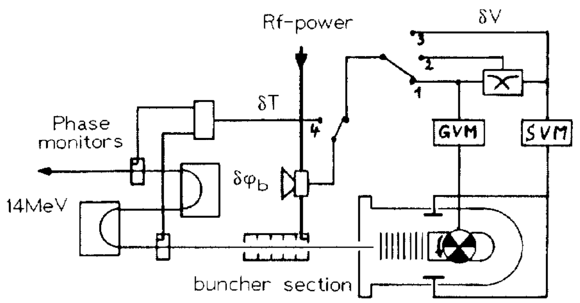

Fig.3: Scheme of the different possibilities for the compensation of the energy fluctuations caused by the preaccelerator. (δT: beam energy fluct., δV: high votage fluct. measured by influence, $\delta\varphi_b$: phase shift of the buncher section)

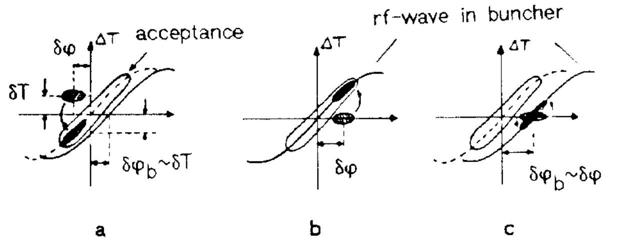

Fig.4: Beam transformation by the 1st buncher section in case of energy and phase errors ($\delta T, \delta\varphi$). Buncher phase ($\delta\varphi_b$) contr by the voltmeters (a&b) and by the beam energy (c).

Alternatively, the stabilisation of the beam energy by a feed back of the energy-signal obtained from the two cavities to the buncher phase has been tried. It turned out, however, that a stable operation was only achieved in case of very small fluctuations of the chopper phase, so that this mode could not be used in normal operation. The reason is, that the compensation of wrong bunch phases is prevented in this case: According to the design of the longitudinal matching to the first microtron long or fluctuating bunches up to ±20° are automatically transformed in the acceptance ellipse. Therefore, energy deviations behind the buncher produced from phase changes are legitimate and must not be corrected, otherwise the injection phase at the microtron entrance gets wrong (s.Fig.4c).

Radiation Influence and Beam Current Limitation

It coud be seen from the beginning that the voltage fluctuations of the V.d.Gr. preaccelerator grew strongly at higher beam currents, so that the current began to oscillate at some value. In order to get intensities in the region of 60μA the Van de Graaff had to be in a very good condition and the accelerator had to be tuned to a beam transmission of nearly 100%.

By comparing the GVM with the energy signal obtained from the time-of-flight measurement, it turned out that the GVM reading is sensitive to x-rays produced from beam losses in the second microtron. Obviously, the radiation is ionizing the insulating gas in the Van de Graaff tank, so that besides the high voltage the GVM sensitivity is reduced by the presence of the charged particles. As a result, the phase of the buncher and the belt charging are driven in the wrong way so that the beam energy is changed. By this, the losses are in general increased and with them the radiation level, leading finally to instability of the accelerator at high beam intensities.

Since most of the experimentalists only needed a current less than 30μA, and since it was planned to replace the Van de Graaff by a rf-linac, no larger efforts were made to increase the maximum beam current.

Troubles

More than 80% of the interruptions and repairs were due to problems in connection with the high voltage generation and faults of the electronical subsystems in the Van de Graaff terminal. Since the probability for breakdowns caused by one flashover was about 30%, the preaccelerator had to be handled very carefully, and during high voltage operation the belt charging had to be limited by a protection circuit.

Breakdowns of the other accelerator components occured relatively seldom compared with the complexity of the system. It seemed unusual, morely, that the regulation transformers of the 30kV klystron power supply and of the power supply for the large microtron magnets had to be replaced twice because of burnt contacts.

Further losses of the available beam time were caused by beam position drifts in the second microtron due to temperature changes of the end magnets: In order to correct the beam position, the experiment had to be interrupted for a few minutes every hour at the beginning of a run and every ten hours, roughly, after two or three days. The warming-up of the magnets to about 30°C was caused by the relatively high coil temperature due to the slow water flow rate of 0.5m/sec and to their "pancake" winding scheme which gave rise to a rather strong thermal contact between water in- and outlet. In spite of a temperature reduction of the cooling water by about 10°C and a removal of copper oxide deposits inside the tubes by means of Prindi-acid, the maximum coil temperature grew from 45°C to 65°C during the four years of operation. Presumably as a consequence of this high temperature, one of the "pancakes" got a short circuit between two windings, so that it had to be replaced. New coils with more efficient cooling are ordered.

With a periodicity of about once per day the rf-interlock system was activated by a relatively fast increase of the current in a ion getter pump at the accelerator sections of the first or second microtron. Immediately after that, the system could be restarted without any indication of a bad vacuum pressure. This effect which occured only during the presence of the beam is still mysterious. It could be merely seen that, preceeding such an event, the pump current rised exponentially for about 20 minutes.

References

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