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HIGH-CURRENT EMITTANCE MEASUREMENTS AT MAMI*

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Abstract

The effects of high beam currents and different types of electron sources on the emittance of the beam at the 3.5 MeV beamline of the Mainzer Microtron MAMI were observed. A thermionic BaO source and a GaAs-based photo-source that allows spin polarization were used. In order to measure the beam size, a new type of wire scanner was utilized. The results show maximum normalized emittance values in the order of a few hundred nm rad for both sources, which lies distinctly within the acceptance of the higher energy stages of the accelerator [1].

MAINZER MICROTRON

The *MAMI* accelerator consists of four consecutive racetrack microtrons and is able to provide continuous electron beam currents up to 100 μA at 1.5 GeV. The beam current is limited by the available RF power of the third microtron (RTM3). Using pulsed beam modes with a low duty cycle of 10^{-4} can circumvent this principal limitation.

A main purpose of our investigations was to measure a possible increase of the beam emittance since much higher currents are planned for the new *MESA* accelerator in Mainz [2].

All measurements were done at a kinetic energy of 3.5 MeV at which the beam is already relativistic and therefore has passed the regions where emittance blow-up due to space charge forces may have occurred.

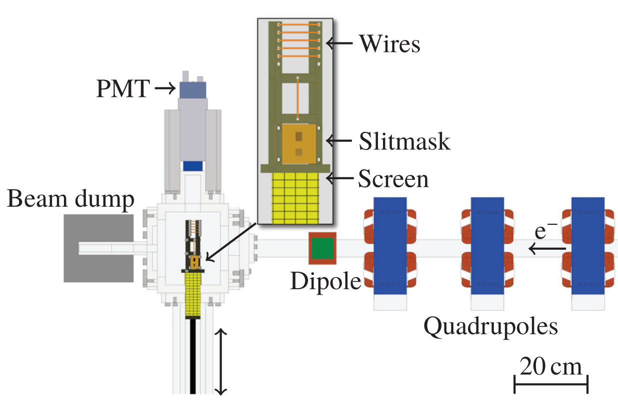

Figure 1: Schematic view of the set-up. The experiment lies behind the 3.5 MeV pre-accelerator of MAMI. The detail view is a close-up of the scanner as seen from the beam direction.

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EXPERIMENTAL SET-UP

The experiments took place at the 3.5 MeV exit beamline of MAMI. The emittance of the beam was measured with the quadrupole scan method [3]. To this end, a new diagnostic tool was developed that allows precise measurements of the beam width at high currents [4]. A sketch of the set-up is displayed in Fig 1. The electron beam enters the set-up from the right and is initially focused by two quadrupole magnets. A third quadrupole magnet is used to perform quadrupole scans. Directly behind the triplet, a small dipole magnet is used to deflect the beam by a maximum of 3 mrad. Using ramp rates of up to 40 mA/μs with the dipole, we have achieved crossing speeds of 54 m/s (horizontal) and 37 m/s (vertical), which means that the duration of a beam size measurement at typical beam diameters of 100 μm can be as fast as only some microseconds if the photon statistics is sufficient at milliampere beam currents. The detected signal is prompt radiation from the beam interaction with the 24 μm tungsten wire that generates luminescent light in a PMT (Fig. 1) which is shielded against the background generated from the beam dump behind the scanner.

To measure the emittance for various beam currents, a pulsed beam mode was used. For this purpose, 10 ns long diagnostic pulses were used which are generated by pulsing the laser current or the control electrode of the thermionic gun, respectively. Due to the low repetition rate of 10 kHz, the crossing speed was reduced to the order of 100 mm/s to have at least ten diagnostic pulses to hit the wire even at the smallest beam sizes.

In this way, a maximum peak current of 160 μA was achieved, while the maximum average current was less than 20 nA. The resulting emittances were compared for two different electron sources. Firstly, a photo-source was used that generates spin-polarized electrons by the stimulation of a GaAs photocathode with a pulsed diode laser [5]. For the photo-source it is expected that changes of the emittance are mainly caused by space charge effects since the emitting area on the crystal stays nearly constant at increasing laser powers. For comparison, the thermionic electron source was also investigated. Contrary to the photo-source, the electron emitting area of the thermionic source increases with the beam current due to the change of the extraction fields at the cathode. This behaviour dictates the resulting emittance of the beam and should prove disadvantageous at higher currents.

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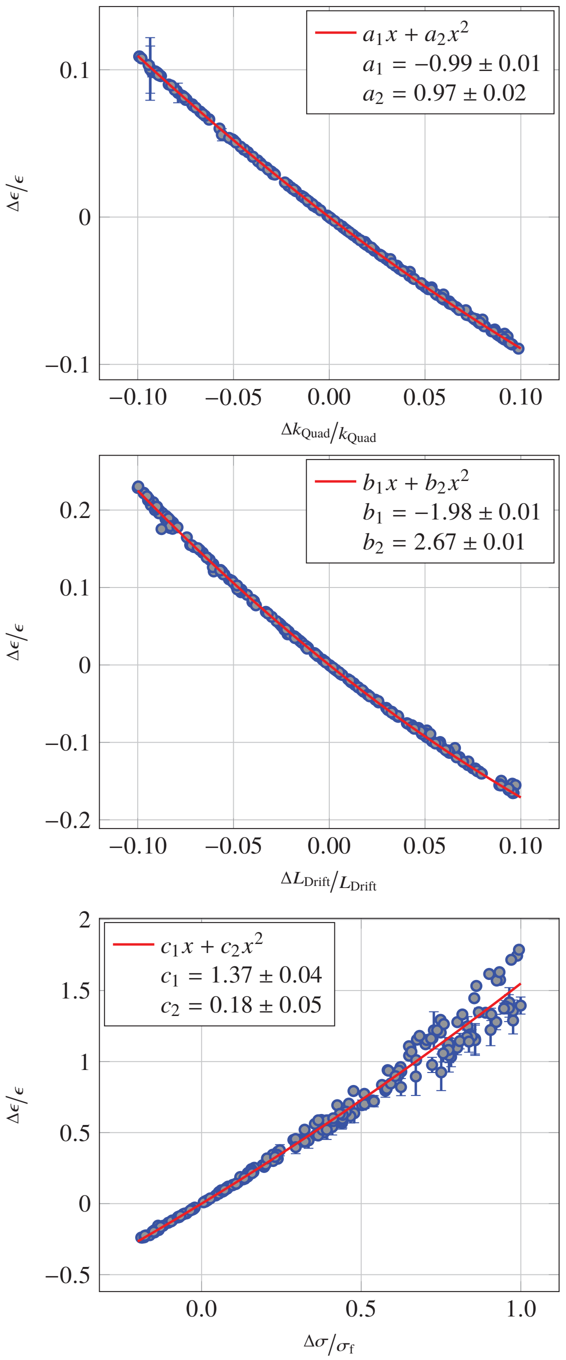

Figure 2: Dependency of emittance errors on measurement errors. From top to bottom: Influence of relative errors of the quadrupole strength, the drift length and the measured beam size.

ERROR PROPAGATION

Due to the complexity of the quadrupole scan method, it proves difficult to describe the propagation of errors analytically. Instead, a numerical approach was chosen and executed with a Monte Carlo simulation. The following list shows the content of the simulation as pseudo-code:

1. Randomized set of emittance ϵ_0, systematic errors, Twiss parameters, drift length, quadrupole strengths and number of measurement points
2. Transformation of Twiss parameters for defined quadrupole strengths
3. Calculation of beam width $\sqrt{\epsilon_0 \beta_1}$, adding systematic error Δx
4. Fit of faulty transfer function to faulty data set
5. Calculation of emittance
6. Comparison of calculated emittance with start emittance
7. 10^6 repetitions of simulation with new value sets

The simulation results (see Fig. 2) show that an error-free quadrupole scan measurement leads to an error-free emittance value. Relative errors of the assumed quadrupole strength and drift length result in relative emittance errors within the same order of magnitude. The error of the beam size measurement $\Delta\sigma$ was assumed systematic (like quadrupole errors, wire thickness or misalignment) and was put into relation to the beam size at the focal point σ_f. Especially at higher beam energies, foci smaller than $\sigma_f = 10\,\mu\mathrm{m}$ are easily achieved. Thus, measurement errors of the beam size must be kept within a few µm to achieve reasonable results of the emittance.

RESULTS

An example of an emittance measurement is shown in Fig. 3. It displays the results for a continuous 20 nA beam that was investigated to prove the readiness of operation of the diagnostic system.

The measured beam sizes show statistical errors below 10 µm and a minimum beam size of $\sigma = (26.6 \pm 3.3)\,\mu\mathrm{m}$. The resulting emittance is (40.0 ± 2.4) nm rad. Tests with different crossing speeds proved the robustness of the experimental set-up to be ready to use at the high-current injector of *MESA* [4].

Figure 3 displays the measured emittances for all currents and electron sources. Additionally, the data is compared to an old measurement performed by Andreas Streun in the year 1986 at 100 keV [6].

The emittance of the photo-source in the vertical direction differs from the emittance in the horizontal direction by about 50 %, which may indicate inhomogeneities of the laser spot[1] or the beam collimation and optics at the space-charge-dominated beam line. However, all of the measured emittance values are distinctly within the acceptance of the accelerator of 0.65 µm rad [7].

Using the thermionic source shows an even greater discrepancy between the emittances in the horizontal direction

[1] The laser to generate the diagnostic pulses illuminates the cathode at an angle of approx. 45° and is not perfectly circular.

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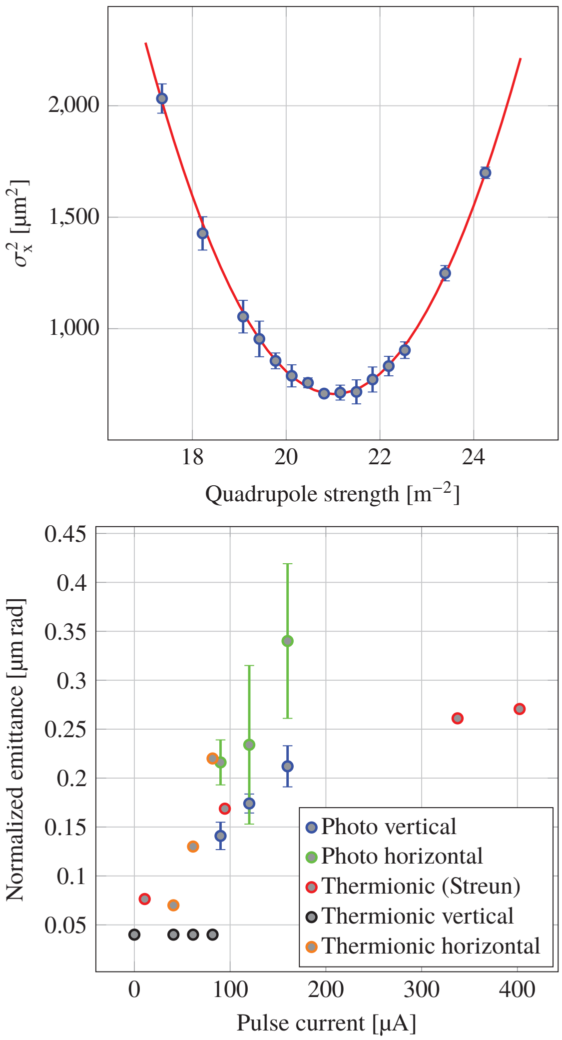

Figure 3: Top: Quadrupole scan of a continuous 20 nA beam at 3.5 MeV. The results show statistical errors of the beam size measurement in the order of a few µm. The normalized emittance of the displayed data set is (40.0 ± 2.4) nm rad. Bottom: Collection of measured emittances at the MAMI accelerator using a pulsed beam. The graph displays the results of the experiment and compares them to an old data set taken by A. Streun in the year 1986 at 100 keV using a continuous beam [6].

with values in the order of 200 nm rad and the emittances in the vertical direction with values distinctly below 50 nm rad. This is not the expected behaviour but could indicate a strong inhomogeneity of the now 15-year-old cathode in combination with asymmetrical beam losses at the space-charge-dominated beam line.

OUTLOOK

Within the next few years, a new energy-recovering superconducting electron accelerator (MESA) will be built at the Institute of Nuclear Physics in Mainz. It is envisaged to operate the accelerator with beam currents up to 10 mA at a maximum energy of 105 MeV. The resulting beam power exceeds the power of the investigated beam by several orders of magnitude. The high crossing speed achievable with the measurement system described here is an advantage. Our simulations [4] seem to indicate that the thermal load on the detection wire can be kept under control for currents of at least 1 mA even in CW operation. However, other issues, like the increased background to be expected at higher beam currents require further investigation.

CONCLUSION

The working principle of a transverse beam diagnostic method for high beam currents was discussed. It was shown that the measurement system is able to perform high-resolution and high-speed beam profile measurements of the MAMI beam at 3.5 MeV.

The emittance using both continuous beam or pulsed beam can be determined, and the results are comparable to old measurements.

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