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TESTING A DIGITAL BEAM POSITION STABILIZATION FOR THE P2-EXPERIMENT AT MESA*

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Abstract

The Mainz Energy-recovering Superconducting Accelerator (MESA) will be built at the institute for nuclear physics at Mainz University. Besides the multi-turn energy recovery mode an external beam mode is foreseen to provide 155 MeV electrons of 85% polarization at 150 μA for parity violating experiments. To achieve the required stability of the main beam parameters a dedicated digital position stabilization is currently developed and tested at the Mainz Microtron (MAMI).

INTRODUCTION

MESA as illustrated in Fig. 1 will provide the opportunity to study precision physics at lower energies but higher beam currents than the accelerator cascade of the Mainz Microtron (MAMI) [1, 2]. The main parameters of the new accelerator are listed in Table 1.

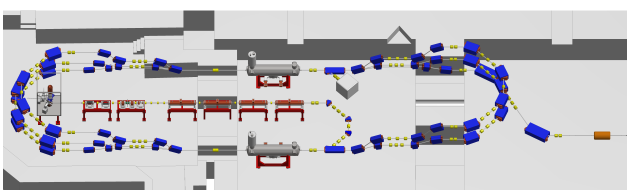

Figure 1: Illustration of MESA.

Table 1: MESA Operation Modes

Parameter stage 1 (2)	EB	ER
Energy [MeV]	155	105
Beam current	150 μA	1 mA (10 mA)
Bunch charge [pC]	0.12	0.77 (7,7)
max. Beam power [kW]	22.5	105 (1050)

Since the very beginning of MAMI (see Fig. 2) RF cavity monitors are used to acquire beam positions and relative phase as well as the intensity of the electron beam [3].

While running the machine for experiments the monitor system delivers CW signals. To optimize the position and phase of the electron beam through the microtrons pulsed beam of high intensity is used to increase sensitivity while reducing the amount of beam losses [4].

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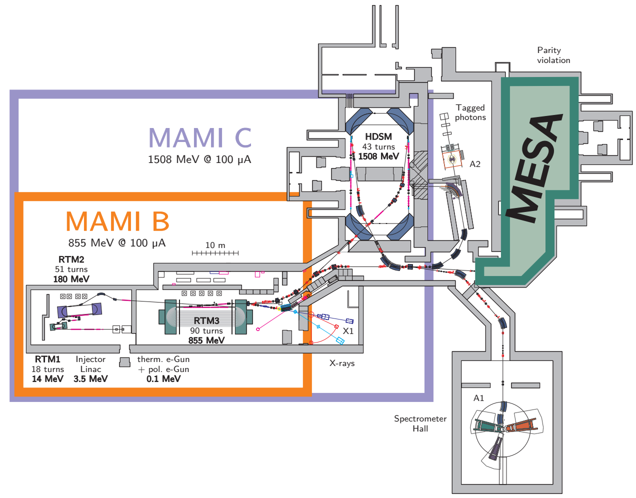

Figure 2: Floor plan of the MAMI accelerator. The space for MESA currently available is marked in green. The test setup at MAMI is installed next to the RTM3 where the beam has an energy of 180 MeV – similar to the external mode with 155 MeV of MESA.

HIGH PRECISION PHYSICS

For high precision parity violating experiments the electron beam has a certain polarization $\vec{P}$. The parity violating asymmetry $A_{\mathrm{LR}} = \frac{n_{\mathrm{L}}-n_{\mathrm{R}}}{n_{\mathrm{L}}+n_{\mathrm{R}}}$ with the two counting rates n_{L} and n_{R} is determined by switching the helicity of the electron beam (usually $\vec{P}_{\mathrm{L}} \rightarrow \vec{P}_{\mathrm{R}}$). Modern experiments like the MOLLER experiment at Jefferson Lab or the P2-Experiment at MESA test asymmetries in the order of 10^{-8} with a precision of a few percent [5, 6]. If for any reason there are smallest inaccuracies while the helicity is switched there is an unwanted helicity dependend modification of the counting rates. This leads to a systematic error called "false asymmetry". To actively minimize this effect different stabilization systems are required, in our case the most important parameters to stabilize are beam intensity, position, angle and relative energy.

Parity Violating Experiments at MAMI

The A4 experiment at MAMI was performed using four RF beam position monitors (horizontal and vertical) together with four fast steerer magnets (both planes also) to achieve a sufficient suppression of helicity correlated position fluctuations of the beam. Another RF monitor is used to measure and stabilize the beam intensity very close to the electron source, another one right upstream of the target monitors the beam intensity for the experimental run control. For a single experiment at 315 MeV at 20 μA and approximately

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1000 hours of beam time the data analysis of the A4 experiment reached a systematic error of less than 100 nm due to helicity correlated fluctuations [7]. However, the analog electronics of the system with only the amplification parameters of each pair of steerer and BPM to be set is not flexible enough for MESA. Going digital would take into account that all upstream steerers affect the beam position at a certain RF monitor. The resulting digital feedback loop is based on a matrix representation of the whole feedback system compared to multiple scalar analog feedbacks and allow for better control of the feedback loop.

Planned Experiment at MESA

For the upcoming P2-Experiment at MESA the demands on the required beam position stability are up to two magnitudes higher compared to A4 at MAMI. A preliminary analysis of the sensitivity of the P2-Experiment with respect to beam parameter fluctuations has revealed that helicity correlated position and angular fluctuations are more critical than intensity and energy variations. We therefore concentrate our efforts on the transverse stability. For this reason we are testing the possibilities of FPGA based feed back loops at one of our experimental beam lines (SFX1). In order to suppress theoretical uncertainties the P2-Experiment is planned for a very low beam energy of 155MeV. To approach this energy in our test we can use the MAMI accelerator at 180 MeV simply bypassing the RTM3. The installation extends from the 180 MeV injection beam line of the RTM3 (passing it) into the extraction beam line of the RTM3 which is operated at 180 MeV for this experiment. A sketch of the installation is given in Fig. 3.

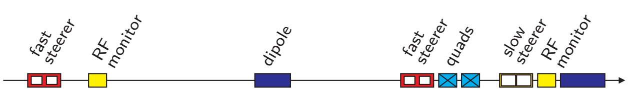

Figure 3: Sketch of a part of the test beam line with the most important elements. The beam is guided from left to right.

TESTS OF COMPONENTS FOR DIAGNOSTICS AND FEEDBACK

The RF cavity monitors along with the fast steerer magnets have all been installed at MAMI and are fully operational. We have installed two different kinds of steerer magnets: one horizontal/vertical pair of iron yoke magnets which are considered slow and two pairs of ferrite based magnets with a special glass beam pipe to reduce eddy currents and therefore yield a higher bandwidth.

Electronics, Digital Systems and Test Setup

The 2.45 GHz cavities ($Q_L \approx 5000$) deliver RF output signals with power $P = ki^2\Delta x^2$ with the intensity i, the position deviation Δx and a constant k. The power ranges from few nW up to mW at a bandwidth of a few MHz. Converting this RF output to the base band and amplifying it yields a voltage $U = k'i\Delta x$ were the position can be found easily if i and k' are known. A schematic drawing is shown in Fig. 4. With this electronics we typically obtain a calibration constant k' between 0.5 and 1 V/mm/μA resulting in micrometer resolution at beam currents of 100 μA or higher. As the RF frequency of MESA will be 1.3 GHz we will need to rescale the present RF monitors of MAMI for MESA – probably operating on the second or third harmonic of 2.6 GHz resp. 3.9 GHz.

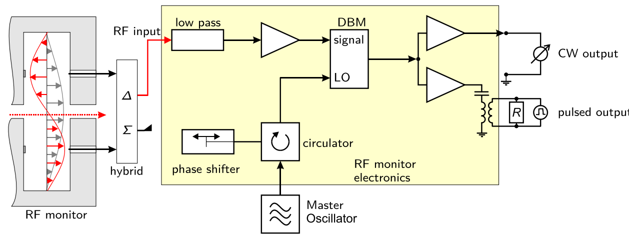

Figure 4: Illustration of the RF monitor electronics. The beam excites the fundamental mode of the resonator at 2.45 GHz. This RF power is converted to a voltage which can be monitored for CW beam or for pulsed beam.

For the test setup we used four Red Pitaya (RP, [8]) boards to acquire the signals of three RF monitors (two BPMs horizontal and vertical each along with one intensity monitor) and to operate the steerer magnets (Figure 5). The RPs are based on the Xilinx Zync-7010 which combines a dual-core processor and a FPGA and are equipped with two fast analogue inputs and outputs. The maximum sampling rate is 125 MS/s at 50 MHz analog bandwidth. For synchronization of the RPs an additional FPGA (Spartan 6) is used as a trigger board, which is controlled by a Raspberry Pi [9]. The run control software running on the RPs was developed in-house. The RPs are originally delivered with an FPGA firmware which suited the needs of data acquisition for the first beam time.

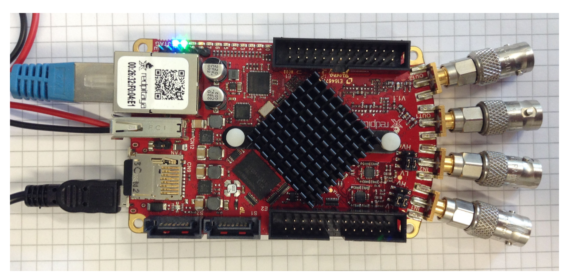

Figure 5: Red Pitaya board.

For future beam times a new firmware will be developed that will allow for feed-forward compensation of helicity correlations of beam parameters as well as reduction of beam fluctuations by feedback control.

First Tests of the Installation with Beam

The first tests with electron beam were used to commission the newly installed RF monitor and steerer magnets along with the full setup of the four Red Pitayas, trigger board and run control. To power the steerer magnets we used a self developed amplifier. The frequency range of this amplifier

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is well above 20 kHz – enough to test the frequency ranges of our steerer magnets.

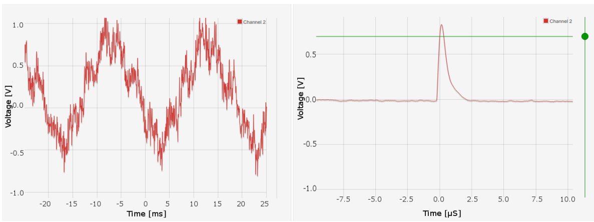

Figure 6: Signals RF monitors: Left side shows 8 μA CW with its characteristic 50 Hz ripple, right side shows a diagnostic pulse of 10 ns being lengthened by the limited bandwidth of the analog electronics. Both shots were performed with the original FPGA firmware.

With our first firmware of the FPGA in combination with the trigger board the synchronized data acquisition was working as expected. In order to wobble the beam we used only one channel (of four) at a time and adjusted all settings (centering of the beam position, wobble amplitude etc.) to avoid clipping of the signals using the original FPGA oscilloscope web interface again. An example is shown in Fig. 6. For each frequency data was taken by our own run control software to characterize the transfer function of the whole system. An FFT is show in Fig. 7 as example.

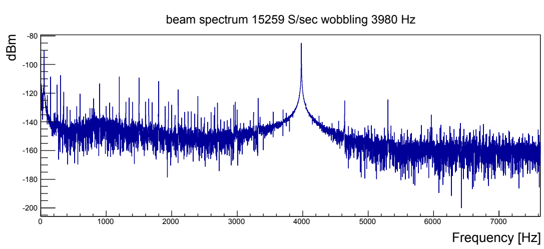

Figure 7: FFT extracted from the run control data while the beam is wobbled with 3980 Hz.

That information is used to optimize both the acquisition system and the power supplies for the steerers. It also can be used to perform numerical calculations of the control loop while the FPGA firmware will be designed. The final development will be able to determine the transfer function automatically by simply sweeping the frequency of the steerer magnets.

FURTHER INSTALLATIONS TO TEST

The beam line at SFX1 can be extended with installations to be tested before being used for MESA. The P2-Experiment will use an atomic hydrogen trap to continuously monitor the polarization of the beam. This trap consists of a superconducting solenoid of up to 8 T. As soon as the solenoid is installed at the beam line the beam position stabilization will be extended with two more RF monitors and steerer magnets to study the behavior of the beam within the strong solenoid.

SUMMARY & OUTLOOK

To successfully operate an experiment like P2 the beam stability needs to be excellent in terms of intensity, energy and beam position. The current experimental setups help us to improve the well proven installation of the A4 experiment: increasing the beam current from 20 μA to 150 μA will significantly increase the sensitivity of the RF monitors, replacing the old RF monitor electronics with modern components reduces the remaining noise and going digital means to be more flexible (feedback and also feed-forward). In addition the digital feedback system developed for the beam position stabilization can easily be adopted to provide beam intensity stabilization and energy stabilization.

The main components for the test setup of the digital beam position stabilization system at MAMI are installed. The next task will be to develop the FPGA firmware to stabilize the beam position as of now only synchronized readout is possible. When the test setup at SFX1 operates as desired the present setup at the A1 Experiment (spectrometer hall) at MAMI will be upgraded and the digital feedback is used under realistic conditions. This routine operation will give the opportunity to study the possibilities and problems from which it should be possible to project if the requirements for the P2-Experiments can be met as soon as MESA is available.

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