THE NEW ORBIT CORRECTION SYSTEM AT ELSA*

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Abstract

ELSA is a fast ramping stretcher ring currently supplying polarized electrons with energies up to 2.4 GeV. To preserve the degree of polarization, the vertical orbit needs to be continuously corrected during beam acceleration. The acceleration is usually performed within 300 ms, with a maximum ramping speed of 6 GeV/s. We aim to achieve a vertical rms deviation not exceeding 50 μm all along the fast energy ramp. In the near future we plan to accelerate polarized electrons up to 3.2 GeV. Therefore, both the power supplies and the corrector magnets have been currently upgraded: first, new power supplies working with a pulsed transistor H-Bridge were developed and successfully installed. Additionally, the existing vertical corrector magnets will now be replaced by newly developed ones. In our contribution, we will present the new correction hardware supplemented by the beam position monitors and their readout electronics.

INTRODUCTION

The stretcher ring is the main part of the polarized electron accelerator facility ELSA. In standard operation multiple injections of polarized electrons at 1.2 GeV are accumulated and then accelerated to 2.4 GeV. Afterwards a slow resonance extraction phase follows. Usually acceleration is performed with a rate of 4 GeV/s within 300 ms, and the extraction phase lasts a few seconds (see Figure 1).

The initial degree of polarization at injection is approximately 72%. In order to preserve this degree of polarization, it is especially necessary to compensate the so called **integer resonances**: During acceleration, every 440 MeV the spin tune becomes an integer and the spins precess in phase with a harmonic of the revolution frequency. Horizontal magnetic field components, periodically acting with this frequency will then lead to depolarization. To compensate for this effect, harmonic field distributions are applied in addition to the general closed orbit correction.

Reducing remaining horizontal magnetic fields plays a major role in polarization conservation. Vertical orbit displacements in quadrupole magnets lead to horizontal magnetic field components, hence the central goal is to keep especially the vertical orbit as flat as possible. Therefore, the beam should be steered through the magnetic centers of all quadrupole magnets.

Without the use of dedicated techniques for polarization conservation the remaining degree of polarization after the acceleration would be lower than 40 %.

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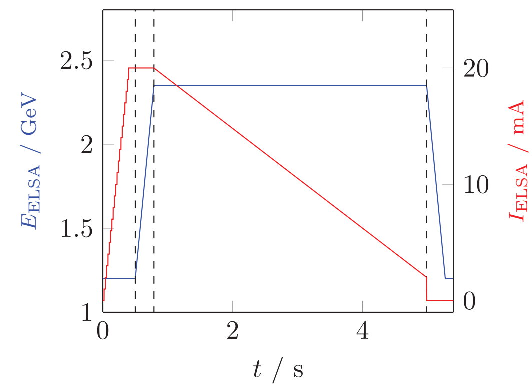

Figure 1: For the first 500 ms several injections are accumulated, followed by a fast energy ramp (4 GeV/s). For the next four seconds the circulating current is continuously extracted by slow resonance extraction. After that the energy is ramped down and a new injection is prepared.

THE ORBIT CORRECTION SETUP

For the upcoming experimental program at ELSA it is planned to accelerate polarized electrons up to 3.2 GeV, which requires a complete upgrade of our orbit correction setup. For precise closed orbit corrections first of all a fast Beam-Position-Monitor-system (BPM) with a good resolution and long term stability is required. Fortunately our BPM-system already provides these features [1]. Also, it became clear that for the planned energy upgrade the vertical corrector strength should be three times higher compared to the system which is currently in operation. Furthermore the harmonic correction scheme demands a substantial improvement of the dynamics of the system. All this was finally achieved by in house developed power supplies [2] optimized for vertical steerer magnets which also were designed by our own staff [3].

Beam Position Monitors

Each of ELSAs 32 quadrupole magnets is equipped with an in-house developed four-button monitor chamber. These are mechanically fixed to the geometric center of the magnets with a precision of $\pm$ 0.2 mm. The remaining position offsets are measured by beam based alignment techniques [4] and are then removed by software calibration. In order to keep the RF-signal cables short, the readout electronics are placed nearby the BPMs. The readout stations are arranged in four subgroups and connected via Controller-Area-Network-Bus (CAN) to a dedicated Linux-PC processing the raw data and calculating beam positions. During booster mode operation online measure-

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ments of the closed orbit can be accomplished with a rate of a few Hz, hence not sufficient for measuring dynamic effects during the fast energy ramp. However the stations can be switched to a special readout mode: The internal readout rate is increased to 1 kHz and position data is stored locally in the readout electronics of each BPM. Up to 4095 data points can be stored, thus the development of beam displacements during the first four seconds (covering the injection, ramping and a large period of the extraction phase) of the ELSA cycle is available.

Steerer Magnets

In order to preserve the ability to perform orbit and harmonic corrections at energies up to 3.2 GeV a new design for the vertical corrector magnets became necessary. In 2003, a new C-shape geometry for the magnet yokes was developed, depicted in figure 2.

In the design phase two important parameters needed to be optimized: An integral corrector field strength $\left(\int B \, \mathrm{d}s\right)$ greater than 9.6 mT is needed. Additionally, the field rising time must not extend 70 ms to be capable to deal with the worst case situation where the harmonic correction demands a complete field reversal between two integer resonances[1]. Further consideration was given to field homogeneity and the fact that in several of ELSAs half cells the overall dimensions for installation of the magnets are quite narrow. In order to prevent for eddy currents when fast field changes are requested, the yokes are composed out of more than 300 thin metal sheets isolated against each other. In the following table the final characteristics are summarized:

Table 1: Characteristics of the new vertical corrector magnets

voltage	200	V
max. current	8.0	A
inductance	260	mH
max. field	40	mT
field integral	**9.8**	mT m
field reversal time	**20**	ms
weight	30	kg
dimensions	25x30x15	cm^3

Power Supplies

The harmonic correction scheme requires that the power supplies have a slew rate which is greater than 0.2 A/ms while driving the magnet coil[2], as well as an absolute current precision of about $\approx$ 0.1 %. Furthermore a shared ramp trigger together with the ability to store individual current ramps locally on every power supply is mandatory. In order to carry out the so called harmonic correction during the energy ramp arbitrary waveform capabilities are required. At a ramping speed of 6 GeV/s the energy ramp

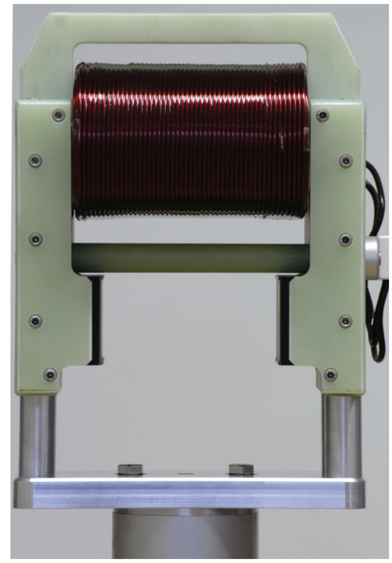

Figure 2: New vertical corrector magnet.

lasts about 300 ms, so a current ramp with 250 support points with minimal time steps of 1 ms is considered to be sufficient. In the top part of figure 4 an example of desired current values is shown. For further explanation of the harmonic correction scheme see [5].

All in all 54 power supplies are needed (24 powering the trim coils in the 24 bending dipoles for horizontal correction and 30 for vertical orbit correction[3]). Based on all these requirements and a comprehensive analysis of commercially available power supplies it was decided to design and assemble the power supplies in house. A key decision in the design phase was to use a pulsed full H-bridge consisting of 4 NMOS-transistors. Together with an dedicated *proportional-integral controller* unit (PI controller) and an CAN-Bus driven communication device all these are housed in one 19 inch crate.

Pulsed transistor bridges (see figure 3) are quite common in AC/DC motor control applications, their use for driving precise magnet fields in corrector magnets is somehow unusual. However in the final analysis they were the only leftover approach which promised to fulfill all requirements.

The operation principle is as follows: The PI controller compares the desired current with the measured current flowing in the magnet coil. Based on the difference, the controller decides if and in which direction the bridge becomes active. Therefor the controller uses pulse width modulation (PWM) of 20 kHz pulses. It produces pulses with a width depending on the absolute value of the difference. These pulses either open the transistors 1 and 4 if the current through the coil needs to be increased, or 3 and 2 if it has to be decreased. Usually the bridge only drives the coil for a very short time ($\approx 3\ \mu$s), during the rest of the 50 μs the current flows freely through the upper or the

[1] At a ramping speed of 6 GeV/s the time between two integer resonances (every 440 MeV) is: $\frac{440\ \mathrm{MeV}}{6\ \mathrm{GeV/s}} \approx 73$ ms

[2] The required rising time for a complete current change at a ramping speed of 6 GeV/s is: $\frac{16\ \mathrm{A}}{73\ \mathrm{ms}} \approx 0.22$ A/ms

[3] ELSA has 32 quadrupole magnets so one would aim to install also 32 correctors in each plane. Due to limited space in several locations only 54 correctors can be used.

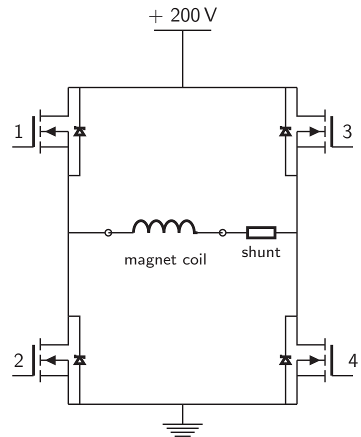

Figure 3: H bridge: Four NMOS transistors STY140NS10 are arranged like the four legs of the letter H, the magnet coil together with a shunt resistor taking the place of the horizontal bar.

lower part of the bridge. For a deeper insight into the power supply design see [2].

STATUS

The upgrade of our orbit correction system is almost completed: All power supplies are successfully in operation and the first 16 new vertical corrector magnets are already installed. For the installation of the remaining magnets it is necessary to construct mechanical supports individually for each location, which is currently in progress. These will be installed one after the other in the near future.

Figure 4 displays the status of the orbit correction system. During the described time span the energy is ramped from 1.2 GeV to 2.4 GeV with 4 GeV/s. In the top part the development of the measured currents of two vertical corrector magnets is shown. In this example, VC24 is a new magnet version, VC26 is an old one. The narrow spikes overlaying the measurements are caused by electromagnetic interference (EMI) generated by the fast switching transistor bridge. However further studies showed that the actual current which flows through the magnet coil is not affected. In order to reduce the intense noise, the bridge modules are connected via screened cables to the magnet coils.

The lower part of the figure shows the response of the vertical closed orbit, measured by the fast BPM readout system. Each trace belongs to the readout of one of the 32 BPMs. The three bumps correspond to the harmonic corrections which are needed every 440 MeV for polarization preservation [5].

The new orbit correction system clearly outreaches the minimum requirements: The rising time of the corrector magnets is three times faster. Also we measured a slew rate of 2.5 A/ms for the new power supplies when connected to new magnets. This is actually one order of magnitude

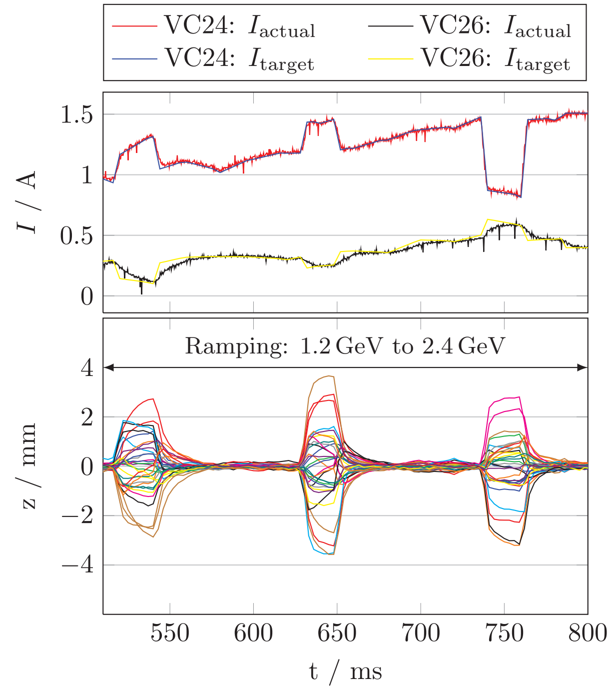

Figure 4: Status of the corrector system: In the top part the target and actual currents of two exemplary chosen vertical correctors are shown. These are the currents for vertical orbit correction superposed with additional currents for harmonic correction at three well-chosen energies. In the lower part the development over time of all 32 vertical beam positions is plotted.

higher than the calculated absolute minimum. These improved dynamics allow for orbit corrections with rms orbit displacements lower than 50 μm in between the harmonic bumps.

With the upcoming finalization of the upgrade process, our closed orbit correction setup will be well prepared for acceleration of polarized electrons up to 3.2 GeV.

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