DYNAMIC CLOSED ORBIT CORRECTION DURING THE FAST ENERGY RAMP OF ELSA*

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Abstract

ELSA is a fast ramping stretcher ring supplying polarized electrons to hadron physics experiments. To preserve the degree of polarization, it is necessary to continuously correct the vertical orbit when accelerating the beam from 1.2 GeV to 2.4 GeV. Acceleration is performed within 300 ms, thus with a ramping speed of 4 GeV/s. During the acceleration, beam positions are measured at a rate of 1 kHz using 32 beam position monitors, which are mounted close to the quadrupole magnets. The demanding task is to achieve a vertical rms deviation not exceeding 50 μm all along the fast energy ramp. Therefore, dynamic orbit corrections are applied by means of offline feed-forward techniques, driving 31 vertical steerer magnets which can change currents in less than 10 ms. In our contribution, we show the used concepts and the implementation of the precise closed orbit correction system at ELSA.

INTRODUCTION

The ELSA stretcher ring is the main part of the polarized electron accelerator facility in Bonn. Typically multiple injections of polarized electrons at 1.2 GeV are accumulated and post accelerated to 2.4 GeV. Afterwards a slow resonance extraction phase follows. Usually acceleration is performed with a rate of 4 GeV/s, thus within 300 ms, the following extraction phase normally lasts for a few seconds. See Fig. 1.
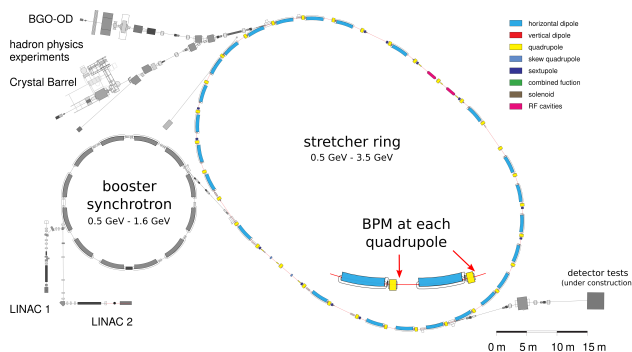

Figure 1: The ELSA accelerator facility.

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 **imperfection resonances**: During acceleration, ev-

ery 440 MeV the number of spin precessions per turn becomes an integer. Remaining horizontal magnetic field components will then lead to depolarization. Without the use of dedicated techniques for polarization conservation the remaining degree of polarization after the acceleration would be lower than 40 % [1].

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. As a consequence it is essential to calibrate the zero positions of every Beam Position Monitor (BPM).

Along with other correction techniques a final degree of polarization of approximately 65 % is preserved.

ORBIT CORRECTION SCHEME

For closed orbit correction during the energy ramp a three step scheme is used:

First the accelerator has to be operated in storage mode. Orbit displacements are measured at chosen storage energies in order to calculate corrector kicks as a basis for interpolated corrector ramps.

As a second step, the accelerator is switched to booster mode. The previously compiled interpolated corrections are applied during the energy ramp. Additional magnetic fields, mostly induced by eddy currents in the wall of the vacuum chamber, still cause remaining orbit displacements. Again these are measured and additional corrector kicks are calculated. This procedure is referred to as *dynamic correction* and represents the second orbit correction step.

In order to reduce remaining horizontal field components which are driving the depolarizing resonances an additional harmonic field distribution is applied. This has to be determined empirically and is called *harmonic correction* [1].

Beam Position Monitors

Each of the 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 (see Figure 3). The remaining position offsets are measured by beam based alignment techniques [2] and are then removed by software calibration.
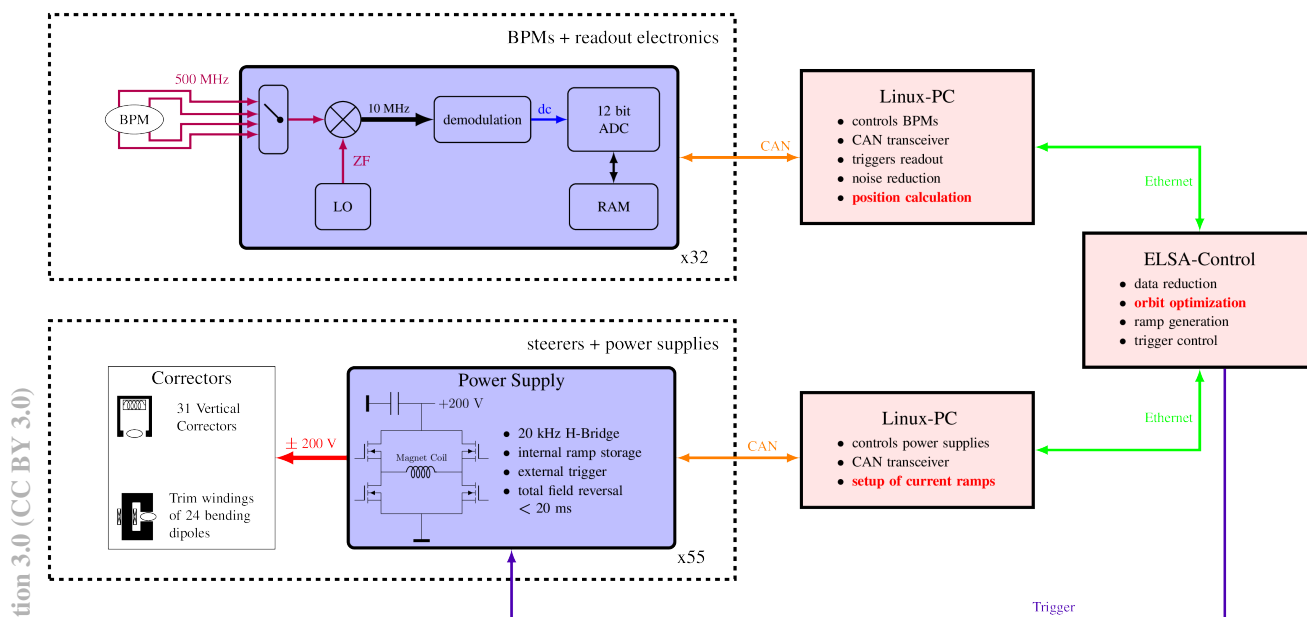
Figure 2: Schematic overview of the closed orbit correction setup. Beam positions are measured and digitalized at 32 BPM stations and then transported to the top level accelerator control system. Here, orbit corrections are calculated and applied via 55 programmable power supplies to 31 vertical corrector magnets and 24 extra trim windings at the bending dipoles for horizontal correction. [3]

Figure 2 shows a schematic overview of the orbit correction setup: In order to keep the RF-signal cables short, the BPM-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. Via Ethernet this PC is connected to the ELSA control-system, where the orbit calculation and the computation of corrector kicks are performed.

In normal operation mode the data of the BPMs is sent to the control system with a rate of a few Hz, hence not sufficient for measuring dynamic effects during the fast energy ramp.

Table 1: Technical data of the installed BPM electronics [4]

BPM electronics		
max. acquisition rate	1	kHz
memory	4096	positions
data transfer	1	Mbit/s
ADC	12	bit
resolution		
absolute	100	μm
relative	5	μm

Corrector Setup

As horizontal steerer elements the so far unused trim windings of the 24 dipole magnets are now successfully in operation, supplemented by 31 corrector dipole magnets to correct orbit displacements in the vertical plane (see Fig. 3). Both steerer types are driven by new in-house developed programmable four-quadrant power supplies. Current ramps can be stored locally at every power supply, these are synchronized via a hardware trigger gearing the start of the energy ramp (for further information see [5]).

Dynamic Orbit Correction

The so-called dynamic orbit correction requires high-resolution measurements. The BPM stations are 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
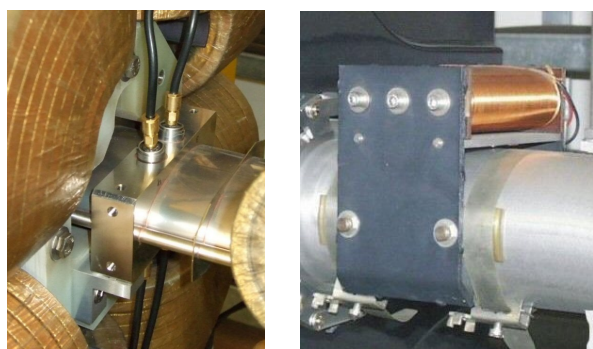

Figure 3: Left: 32 BPMs are installed as close as possible to the geometric center of every quadrupole magnet. Right: 31 small corrector dipole magnets are used for vertical orbit correction (old setup).

during the first 4 seconds (covering the injection, ramping and a large period of the extraction phase) of the ELSA cycle is available. After all data is taken, it is transferred to the ELSA control system where new corrector ramps are calculated to minimize the residual orbit distortions. To reduce computation time of the new orbit correction the measured data of the BPMs are reduced to time bins with configurable width (typically 20 ms).
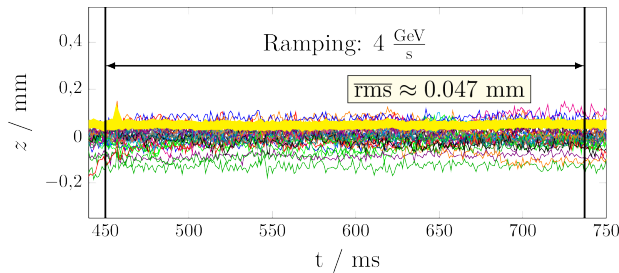

Figure 4: Dynamic closed orbit correction during the fast energy ramp. Example: Development of vertical beam displacement at each of the 32 BPMs (bold yellow: rms)

These 55 new corrector ramps are then locally stored at the corresponding corrector power supplies. From this point, the programmed corrector ramps are applied for every following acceleration cycle. By means of this feed forward technique a long term stable, nearly flat closed orbit can be provided. Figure 4 shows the development of vertical beam displacement along the energy ramp for each of the 32 BPM traces after a successfully accomplished dynamic orbit correction. The vertical rms deviation of approximately 50 μm is regularly achieved.

Usually the described procedure has to be carried out only once every few days.

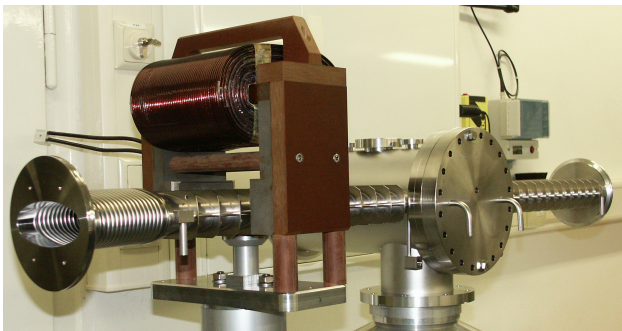## UPGRADE OF CORRECTION SETUP

Figure 5: Prototype of the new vertical steerer magnet.

The existing correction setup is suitable for use at extraction energies up to 2.4 GeV. At higher energies, the vertical correction magnets can not provide the required field strength. Actually field saturation is already a problem at 2.4 GeV. The planned upgrade to accelerate polarized electrons up to ELSAs maximal energy of 3.2 GeV demands

for revised vertical corrector magnets [6] together with new four quadrant power supplies [5].

The installation of these newly developed steerer magnets (see Figure: 5) with optimized dimensions and corrector strength is currently prepared; meanwhile, the old system's magnets are still in use. At the moment all 55 new power supplies are successfully in operation.

Table 2: Comparison of vertical corrector characteristics: currently using the old system. In the near future the newly developed magnets will be installed.

Vertical Corrector System			
	old	new	
voltage	20	200	V
max. current	1.5	8.0	A
inductance	220	260	mH
max. field	15	40	mT
field integral	3.2	9.8	mT m

CONCLUSION

Precise control over the closed orbit is a basic requirement for preservation of polarization at ELSA. During the fast energy ramp (typically 4 GeV/s) sophisticated methods are applied in order to preserve as much of the initial degree of polarization as possible.

Closed orbit corrections that are based on static measurements and then scaled linearly with the ramping energy are not sufficient. As a second iteration, the linear interpolated corrections are improved by means of feed forward applied additional dynamic corrections.

With these two correction steps a long-term stable vertical rms deviation of better than 50 μm is achieved. In the near future the installation of new vertical steerer magnets will be finished. The closed orbit correction setup at ELSA will then be well prepared for acceleration of polarized electrons up to 3.2 GeV.

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