PRECISION CLOSED ORBIT CORRECTION IN A FAST RAMPING STRETCHER RING

Andreas Balling#, Andreas Dieckmann, Frank Frommberger, Wolfgang Hillert
Electron Stretcher Accelerator (ELSA), University of Bonn, Germany

Abstract

Acceleration of polarized electrons in a fast ramping circular accelerator poses challenging demands on the control and stabilization/correction of the closed orbit and the vertical betatron tune, in particular on the fast energy ramp. In order to successfully compensate depolarizing resonances at a ramping speed of up to 7.5 GeV/sec (d*B*/d*t* = 2 T/sec), at ELSA the closed orbit is stabilized with high precision using a system of Beam Position Monitors and steerer magnets distributed along the ring. During acceleration, the beam positions are read out from the BPMs at a rate of 1 kHz and energy-dependent orbit corrections are applied accordingly by means of offline feed-forward techniques. The system is thus sensitive to dynamic effects and an orbit stabilization of 100 microns rms is achieved routinely. At the same time, the betatron tunes are stabilized to 0.01 by time-resolved tune measurement and appropriate manipulations of the machine optics. This presentation will cover the concepts and implementation of techniques for orbit stabilization required for the acceleration of a polarized electron beam in the fast ramping stretcher ring ELSA.

INTRODUCTION

The ELSA accelerator facility at the University of Bonn [1] consists of a 50 keV source of polarized electrons [2] and two thermionic electron guns, two injector LINACs, a booster synchrotron and the 3.5 GeV stretcher ring (Fig. 1). Electron sources as well as the booster synchrotron are operated at 50 Hz repetition rate. In order to supply a nearly continuous beam to the external hadron physics experiments, several injections from the synchrotron are accumulated in the stretcher ring at typically 1.2 GeV, post-accelerated to the extraction energy of max. 3.5 GeV and then extracted slowly by means of resonance extraction, yielding a macroscopic duty factor of >70%. In 2010, an additional external electron beamline for detector tests will become available to users. For synchrotron radiation experiments, after accumulation and acceleration the beam (100 mA max.) can be stored without extraction.

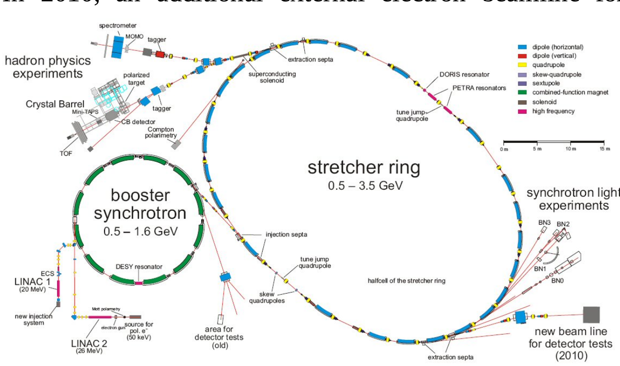

Figure 1: The ELSA accelerator facility.

#balling@physik.uni-bonn.de

DYNAMIC ORBIT CORRECTION

The hadron physics program performed at ELSA is mainly focused on double polarization experiments utilizing tagged photons (linearly and circularly polarized) and a polarized frozen spin target [3]. In order to successfully conduct this scientific program, a high and reliable degree of electron beam polarization as well as a high beam pointing stability on the tagging target are required.

During the fast energy ramp, a sophisticated scheme for the correction of depolarizing resonances is mandatory: betatron tune jumps are applied for compensation of intrinsic resonances and harmonic closed orbit corrections for compensation of imperfection resonances [4]. Depending on ramping speed, these resonances are crossed every 20..50 msec during acceleration. For their compensation, rapidly changing manipulations of the closed orbit as well as of the vertical betatron tune have to be applied.

Prerequisite for these techniques is an accurately controlled and flat closed orbit. At a ramping speed of up to 2 Tesla per second, corresponding to 7.5 GeV/sec, closed orbit corrections that are based on static orbit measurements and then scaled linearly with energy have proven to be insufficient, giving rise to the need for a dynamic orbit correction method.

Beam Position Measurement

Each of the 32 ELSA quadrupole magnets is equipped with a beam position monitor (BPM), which is mechanically fixed to the geometric center of its quadrupole with a precision of ±0.2 mm. The remaining position offset with respect to the magnetic center is measured by means of beam based alignment to ±0.1 mm absolute error, thus calibrating the BPM zero positions [5].

In order to become sensitive to dynamic effects during the fast energy ramp, the system has recently been upgraded: New water cooled vacuum chambers with BPM station (optimized ESRF-type) and ion clearing electrode have been installed (Fig. 2a). The monitors are now read out every millisecond and the position data is stored locally in the BPM electronics (up to 4095 data points per BPM), thus providing high-speed in-situ orbit measurements. After the energy ramp, the data is transferred to the accelerator control system at a speed of 1 Mbaud over a modified CAN bus network (four segments), see Fig. 2b.

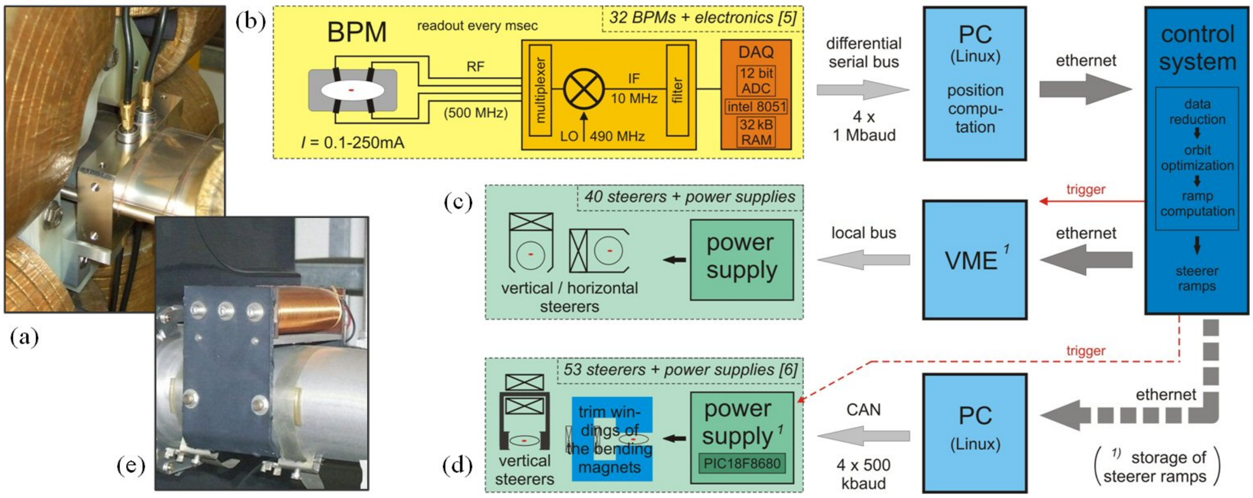

Figure 2: (a) BPM fixed to the center of its quadrupole magnet. Schematic overview of the BMP and the readout (b) as well as the correction scheme for the existing setup (c) and the new system (d). Existing steerer magnet (e).

Orbit Correction Computation and Application

For the purpose of noise suppression the position measurements are firstly averaged over typically 4 or 8 acceleration cycles and the data is then reduced to time bins whose width can be chosen according to the required time resolution (e.g. 20 msec bins have turned out to be sufficient at a ramping speed of 4 GeV/sec).

Based on these time-resolved BPM traces, an individual current ramp for each of the at present 40 steerer magnets (21 horizontal and 19 vertical, see Fig. 2e) is computed. The current ramps are stored in the memory of the VME computer controlling the steerers' power supplies and are then applied every acceleration cycle (Fig. 2c).

Results

Figure 3 shows the development of the vertical beam position during the fast energy ramp at each of the 32 BPMs. The successful orbit stabilization becomes obvious: the rms deviation of the 32 traces from the design orbit is 80 microns, and no individual offset is larger than 200 microns (Fig. 3a).

Figure 3b indicates the long term stability and reproducibility of the orbit control: once a dynamic closed orbit correction has been applied and is then left unchanged, the rms beam position deviation increases by about 10 microns per day. After application of a new dynamic correction (in this case after 4.3 days) the resulting new rms orbit matches the initial one within about 5 microns.

The achieved stability of the beam polarization, measured in the external beamline with the CBELSA experiment's Møller polarimeter, is shown in Fig. 4. The dashed line represents the average value of 63%.

CORRECTION SYSTEM UPGRADE

The existing orbit correction system is suitable for orbit control and resonance compensation up to a beam energy of 2.4 GeV. Above however, it is limited in field strength (due to the current limitation of the power supplies and saturation effects at higher fields the steerers can no longer apply the required orbit bumps) and ramping speed (the time needed for such an orbit bump application exceeds the available time window between two consecutive resonances).

Figure 5c shows the situation for a ramping speed of 4.5 GeV/sec: the period between two consecutive

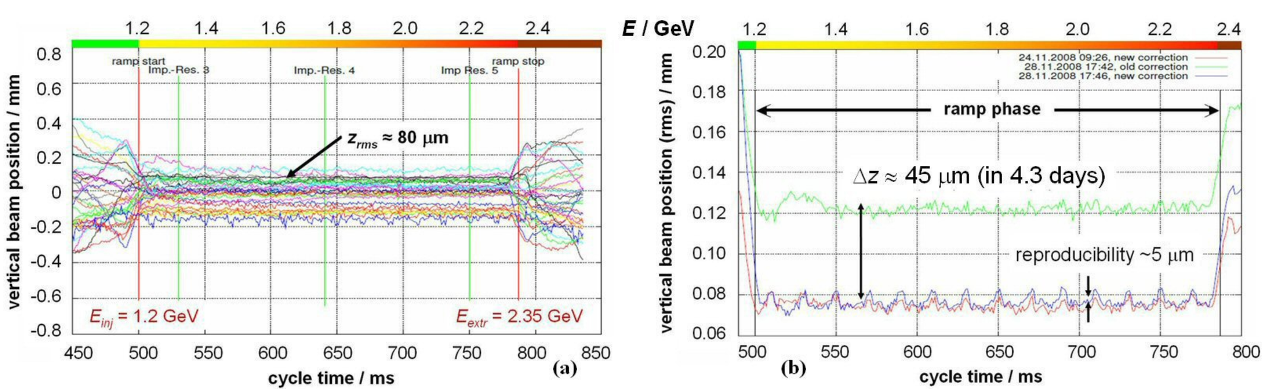

Figure 3: Closed orbit correction during the fast energy ramp: (a) Development of the vertical beam position at each BPM (bold line: rms). (b) Long term stability and reproducibility of the vertical closed orbit rms.

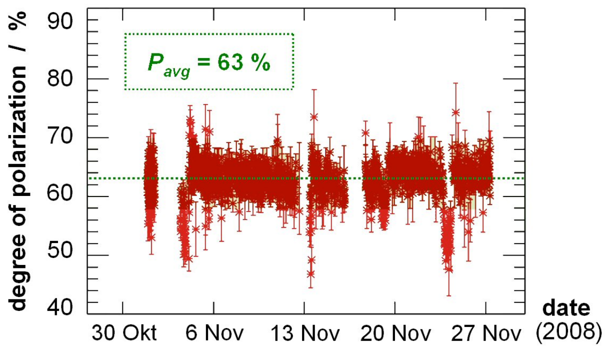

Figure 4: Beam polarization measured during data taking (dashed line: average).

imperfection resonances amounts to less than 100 msec. However, to avoid interference with the betatron tune jump for the compensation of the interjacent intrinsic resonance, the time available for application and withdrawal of a harmonic correction is on the order of 40 msec only. In a worst case scenario, the power supply must therefore be able to perform a jump from minimum current up to maximum current and back down within that period.

In order to sustain the degree of polarization at higher energies a new orbit correction system has been developed [6]: as horizontal steerers the so far unused trim windings of the 24 bending magnets will be utilized, while for vertical orbit corrections 29 newly designed steerer magnets will be installed together with new beam pipe segments optimized for the suppression of eddy currents (Fig. 5a). For both steerer types new programmable four-quadrant power supplies have been developed in-house. Their power sections (Fig. 5b) are based on a 20 (25) kHz H-bridge for the vertical (horizontal) steerers and are operated by microcontrollers of the Microchip PIC18 series. The in total 53 power supplies are connected via four fast (500 kbaud) CAN bus segments to a Linux-PC, which communicates with the top level accelerator control system via LAN (Fig. 2d).

The results achieved for the vertical orbit correction subsystem are shown in Fig. 5c: the available integral field strength has been increased by a factor of three compared to the existing setup and the time required for an orbit bump application has been reduced down to well below 20 milliseconds as required.

CONCLUSION

Essential for the acceleration of a polarized electron beam in a fast ramping stretcher ring is a high precision orbit control. Therefore, the ELSA BPM system has been upgraded and the technique of dynamic closed orbit correction has been implemented into standard machine operation, achieving a stable and reproducible orbit as well as a reliable degree of polarization. In addition, the newly designed orbit correction system will allow for compensation of all imperfection resonances without interfering with the correction of the interjacent intrinsic resonances over the whole ELSA energy range.

ACKNOWLEDGEMENTS

This work is supported by the German Science Foundation (DFG) within the scope of SFB/TR 16 “Subnuclear Structure of Matter”.

REFERENCES

[1] Hillert, W., “The Bonn Electron Stretcher Accelerator ELSA: Past & Future”, EPJ A s01 (2006) 139.
[2] Hillert, W. et al., “The 50 kV inverted source of polarized electrons at ELSA”, AIP Conf. Proc. 570 (2001) 961.
[3] Dutz, H., “Highlights of polarized solid state target instrumentation”, NIM A526 (2004) 117.
[4] Hoffmann, M. et al., “The polarized electron beam at ELSA”, AIP Conf. Proc. 570 (2001) 756.
[5] Dietrich, J. et al., “Control and Data Processing of the Distributed 500 MHz Narrowband Beam Position Monitor System of ELSA”, IEEE, Part vol.3 (1999) 2054.
[6] Balling, A. et. al., “Polarization Upgrade at ELSA”, AIP Conf. Proc. (SPIN 2008, in press).

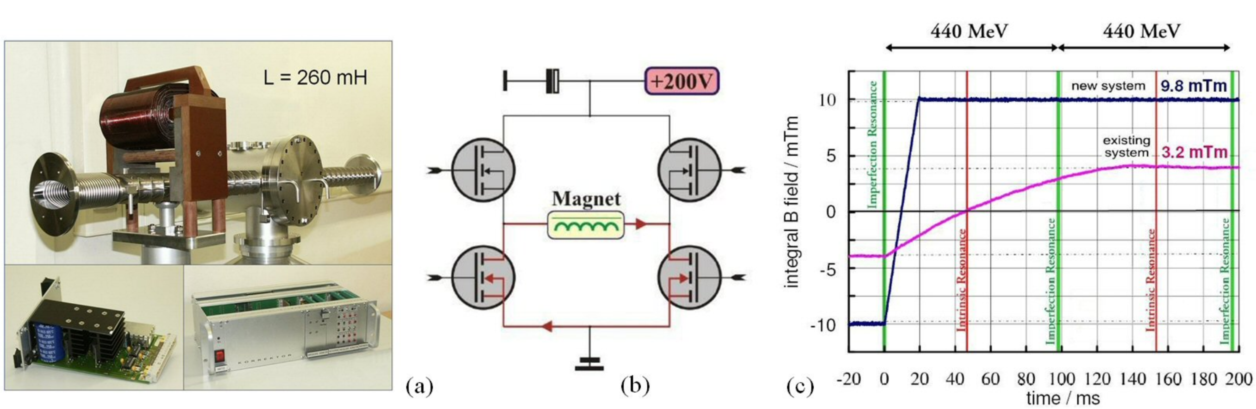

Figure 5: (a) New steerer magnet and beam pipe (top), H-bridge and complete power supply (bottom). (b) Schematic of the pulsed H-bridge, indicating the inductance-driven current loop between two consecutive loading pulses (lower section). (c) Comparison between existing setup and new system (at 4.5 GeV/sec ramping speed).