FIRST MEASUREMENTS WITH MULTIBUNCH FEEDBACK SYSTEMS AT THE FAST RAMPING STRETCHER RING ELSA*

Manuel Schedler†, Frank Frommberger, Nikolas Heurich, Wolfgang Hillert,
André Roth, Rebecca Zimmermann
ELSA, University of Bonn, Nussallee 12, D-53115 Bonn, Germany

Abstract

At the Electron Stretcher Facility ELSA of Bonn University, an upgrade of the maximum stored beam current from 20 mA to 200 mA is planned. The storage ring operates applying a fast energy ramp of 4 GeV/s from 1.2 GeV to 3.5 GeV. The intended upgrade is mainly limited due to the excitation of multibunch instabilities. As a countermeasure, we succesfully commissioned state-of-the-art bunch by bunch feedback systems in the longitudinal and the two transverse dimensions. First results concerning the commissioning of the systems as well as the operation during the fast energy ramp will be presented. In particular, the performance while controlling the motion of every single bunch, especially in controlled bunch cleaning, will be discussed.

ELECTRON STRETCHER ACCELERATOR – ELSA

ELSA is a three-stage electron accelerator. One of the two linear accelerators is used to inject an electron beam of 20 MeV into a fast ramping booster synchrotron to gain an energy of typically 1.2 GeV. The beam can be accumulated and stored in the 164.4 m long stretcher ring, accelerated to a maximum energy of 3.5 GeV and finally slowly extracted to the hadron physics experiments using resonance extraction methods. An overview of the accelerator is given in Figure 1. The typical ramping speed applied in the stretcher ring is 4 GeV/s, yielding to additional requirements for the feedback system, which will be discussed in this proceeding.

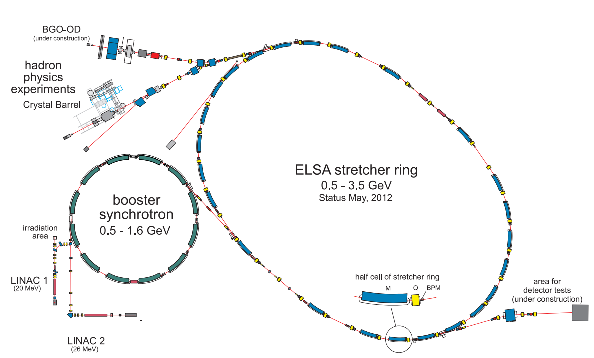


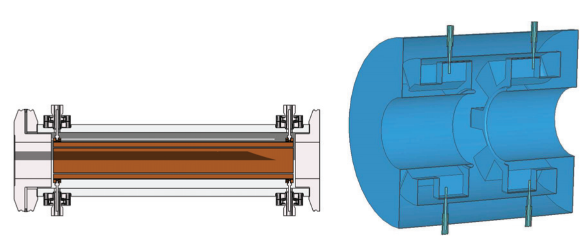
Figure 1: ELSA Facility, Status May 2012

BUNCH BY BUNCH FEEDBACK SYSTEM

In order to enable a stable operation with beam currents higher than a few 10 mA, a state-of-the-art bunch by bunch feedback system is used for damping longitudinal and transverse multibunch instabilities. For each plane a fully operational feedback system is installed, consisting of four major components:

First, a BPM[1] records a signal corresponding to the beam oscillations. Then, the feedback frontend mixes this signal with the third harmonic of the ELSA RF to achieve amplitude or phase demodulation. In case of phase demodulation, the longitudinal displacement of each bunch can be extracted. Using amplitude demodulation allows measuring the horizontal or vertical displacements. A fast ADC converts the signal to digital information. In the following FPGA [1], the temporal changes of position values of every single bunch are continuously analyzed. To do so, a digital band pass filter with a maximum number of 32 taps is used to extract a small part of the power spectrum around the betatron tune which is related to coherent dipole mode oscillations of the bunches. A correction signal is calculated for every single bunch and sent to an RF amplifier, which is connected to a broadband RF kicker. In the longitudinal plane, two kicker cavities are used to actively damp coherent synchrotron oscillations. In the transverse plane damping is performed using a stripline kicker which consists out of four striplines in order to provide horizontal and vertical correction fields. Both, kicker cavity [3, 2] and stripline kicker [4] are in-house developments adjusted to the ELSA RF frequency and bunch length and are shown in Figure 2.

An overview of the feedback system including all major components is given in Figure 3.



(a) Cut through the stripline kicker (b) Cut through the kicker cavity

Figure 2: Stripline kicker and kicker cavity used at ELSA.

* Work supported by the DFG within the SFB/TR 16
† schedler@physik.uni-bonn.de

[1] **B**eam **P**osition **M**onitor

ISBN 978-3-95450-115-1

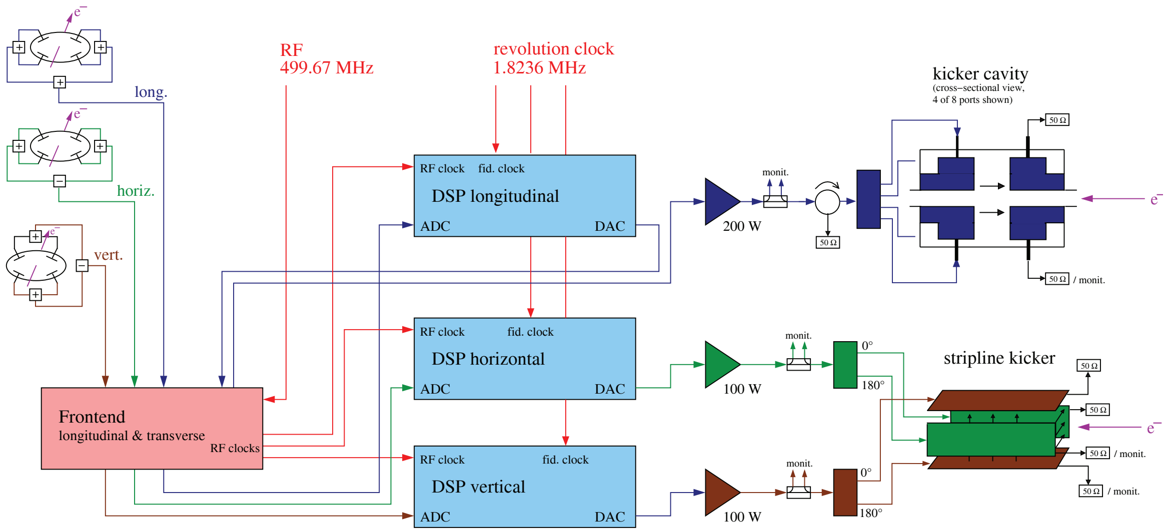


Figure 3: Overview of the three-dimensional bunch by bunch feedback system used at ELSA.

FEEDBACK ON THE FAST ENERGY RAMP

In order to successfully extract the coherent dipole mode oscillations by band-pass filtering, the betatron and the synchrotron tune have to be kept constant during the whole ELSA cycle. If this is not assured, a shift of the bunch's oscillation frequency will yield to a change of the filter's phase and the phase of the correction signal. If the phase shift exceeds 90° the correction signal will no longer damp but excite coherent oscillations. It is therefore of major importance to keep all tunes as constant as possible.

In the longitudinal plane, the tune depends on the beam energy and the overvoltage factor. To keep it constant, the accelerating voltage in the RF cavities is linearly ramped with the beam energy. In the transverse plane, the tune depends on the quadrupole strengths. Due to eddy currents excited by the fast time varying magnetic fields during the energy ramp additional quadrupole fields are generated acting on the beam and changing the tune. As a countermeasure, first the tune is measured by consecutively exciting coherent beam oscillations on the ramp. After that, the quadrupole ramp is modified accordingly to minimize the detected tune shifts [5].

In case of coherent beam instabilities, the spectral representation of the temporal changes of a single bunch's positions will be dominated by a well pronounced peak at the betatron or the synchrotron oscillation frequency respectively. When successfully damping the oscillations with the feedback system, the peak converts to a dip, whose depth can be used as a measure for the quality of the damping process. Typical spectra, derived when the longitudinal feedback was acting on the beam, are shown in Figure 4. The different curves present the development of the spectra and were recorded at different times on the energy ramp from $1.2\,\mathrm{GeV}$ to $2.35\,\mathrm{GeV}$. The tune was kept almost constant during the whole cycle (a small shift was observed and can be read off from the Figure), ensuring an overall damping which is demonstrated by the well pronounced dip in all spectra.

Typical spectra of horizontal position changes of a single bunch during the energy ramp are shown in Figure 5. Without correcting for tune shifts caused by eddy currents, the tune varies while ramping by about $15\,\mathrm{kHz}$. This yields to a flattening of the dip and the generation of an extra peak, indicating an excitation of coherent oscillations caused by an improper phase matching of the band pass filter. Switching on the tune correction changes the situation and allows for a successfully damping of coherent oscillations during the whole ramp, as can be seen in Figure 5(b).

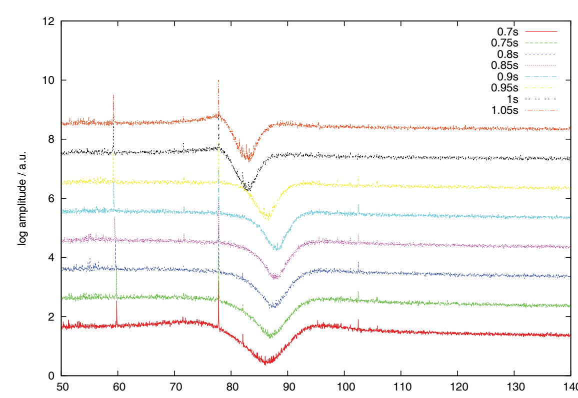
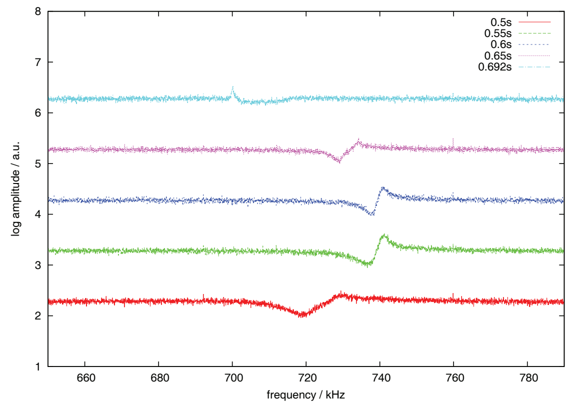


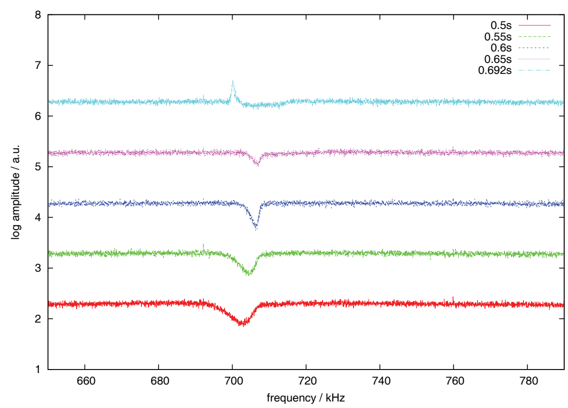
Figure 4: Longitudinal bunch spectrum on the fast energy ramp.

Using this method allows to damp coherent oscillations on the fast energy ramp in any of the three dimensions. Meanwhile the feedback system is successfully operated for beam currents of up to $40\,\mathrm{mA}$. Effects appearing at higher beam currents have to be further investigated.

ISBN 978-3-95450-115-1



(a) bunch spectrum without tune correction



(b) bunch spectrum with tune correction

Figure 5: Horizontal bunch spectrum on the fast energy ramp.

SINGLE BUNCH GENERATION

Calibration of hadron physics detectors requires low beam intensities, which can only be delivered reliably when removing all but one bunches in the stretcher ring before extracting the beam to the experimental area. Bunch cleaning is achieved by excitation of coherent vertical betatron oscillations, leading to beam loss in the affected bunches. To do so, the frequency of the excitation signal is continuously sweeped over a range of (785 ± 2.5) kHz using a sweeping time of $10\,\mu$s and applied to all but one buckets.

Due to the limited insulation between adjacent buckets, caused by the rising and falling times of the kickers, the electrons in the remaining bunch are affected as well. This leads to a further decrease of the beam current, depending on the excitation strength, the filling pattern and the beam current itself. A BPM signal demonstrating a single bunch circulating in the stretcher ring is shown in Figure 6.

ADDITIONAL COUNTERMEASURE

In the case of multibunch instabilities, the number of possible phase advances and therewith the number of different oscillation modes are given by the harmonic number, which for ELSA amounts to 274. Looking at the

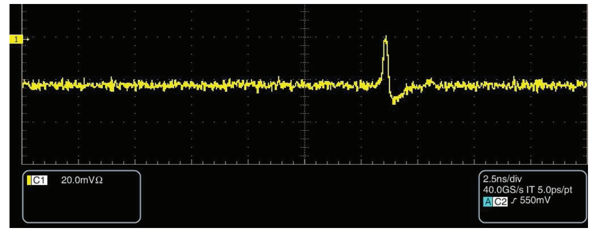


Figure 6: BPM signal of a single bunch stored in ELSA.

beam spectrum, each of these modes corresponds to a specific frequency which can be measured via a BPM. If one of these modes is driven, coherent multibunch instabilities will be excited. In the longitudinal plane, the excitation is mainly caused by HOMs[2] of the two five-cell PETRA cavities used for beam acceleration. In particular the first HOM at 1.46 GHz, which drives the instability mode 253, is one of the most harmfull ones (see Figure 7).

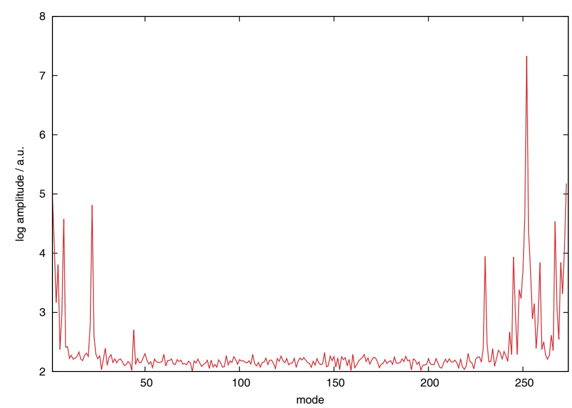


Figure 7: Measrued amplitudes of longitudinal multibunch modes.

In order to increase the damping strength, a small band feedback system using a high Q RF cavity designed for the frequency of the major instability mode will be investigated in addition to the existing broadband feedback.

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[2] **H**igher **O**rder **M**odes