COMMISSIONING OF MULTIBUNCH FEEDBACK SYSTEMS AT THE FAST RAMPING STRETCHER RING ELSA*

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Abstract

At the Electron Stretcher Facility ELSA [1] of Bonn University, an external beam of either unpolarized or polarized electrons is supplied to hadron physics experiments. The ELSA stretcher ring operates in the energy range of 1.2 GeV to 3.5 GeV and achieves a duty cycle of up to 80 % using a fast energy ramp of 4 GeV/s. Under these conditions, an increase of the internal beam current from an actual value of 20 mA up to 200 mA is planned. Such an upgrade is mainly limited by the excitation of multi-bunch instabilities. As one active counteraction, we have installed state-of-the-art bunch-by-bunch feedback systems for the longitudinal, as well as for both transverse planes. The detailed setup with all main components and first results of the commissioning of the longitudinal system are presented.

INTRODUCTION

The ELSA stretcher ring operates routinely with an internal beam current of 10 mA to 20 mA. In the booster operation mode, a fast energy ramp is used before the beam is extracted via a slow resonance extraction to the external experiments within a few seconds, to accelerate the beam up to the extraction energy, ensuring a high duty cycle. In the framework of the future experimental hadron physics program, an intensity upgrade of the external beam of up to 5 nA to 10 nA, which corresponds to an upgrade of the internal beam current of the ELSA stretcher ring of up to 200 mA, is of great interest.

The spectral analysis of beam signals recorded via spectrum analyzer show that, in particular, longitudinal coupled bunch instabilities already occur at currents above 15 mA in the stretcher ring. As one consequence, low frequency intensity variations of the external beam current were observed. Furthermore, at higher currents, the internal beam also became transversely instable. These bunch oscillations are mainly caused by excited undamped monopole and dipole higher order modes (HOM) of the two installed 500 MHz five-cell accelerating cavities of the PETRA type. In addition, ion and resistive wall effects are also responsible for the excitation of instabilities. Overall, these coherent beam oscillations deteriorate beam quality and significantly reduce the storable beam current in the stretcher ring.

* Work supported by German Research Foundation through SFB / TR 16 and by Helmholtz Alliance through HA-101.
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As one counteraction, which is well known from synchrotron light sources and colliders, we installed multi-bunch feedback (FB) systems for all three planes in order to damp the instabilities [2] and to enable the planned current upgrade. FB relevant parameters of the stretcherring are summarized in Table 1.

Table 1: FB Relevant Parameters of the Stretcherring

Energy range	$(1.2 - 3.5)$ GeV
Energy ramp velocity	4 GeV/s
Number of bunches	274
RF frequency	499.67 MHz
Revolution frequency	1.8236 MHz
FB analog bandwidth	250 MHz

SYSTEM LAYOUT

A digital bunch-by-bunch FB consists of the following main components: An analog front-end detecting the phase/position displacement of each bunch, a digital signal processor (DSP) computing a correction signal to damp the oscillations and powerful broadband kickers which apply the correction to the bunches. Since all possible coupled-bunch instabilities appear in the frequency range of half of the RF frequency of the beam spectrum [3], the analog bandwidth of the FB system at ELSA must be at least 250 MHz. Furthermore, due to a bunch spacing of 2 ns, the sampling rate of the DSP must be equal to the RF frequency. An overview of the complete layout of the system is shown in Fig. 1.

BPMs & Front-end

We use button beam position monitors (BPMs) located at three different ring positions characterized by large beta functions for the horizontal and the vertical plane respectively as well as by a zero dispersion for the longitudinal plane. Via broadband (up to 2 GHz) combiners (Minicircuits ZESC/ZFSC-2-11) and $180°$ hybrids (Macom H-9), sum and delta signals are provided for the following analog signal processing in the front-end.

For the front-end and the digital signal processing electronics, we decided to purchase commercially available state-of-the-art modules from the company DIMTEL [4]. The combined front-/back-end (FBE-500LT) consists of

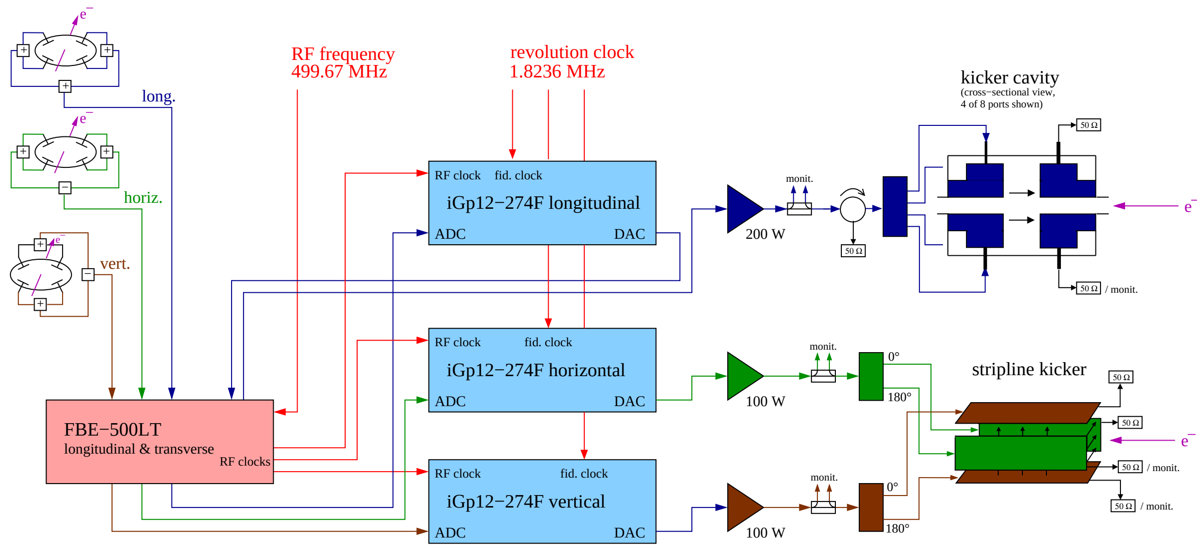

Figure 1: Layout of the bunch-by-bunch FB systems realized for the longitudinal and both transverse planes at the ELSA stretcher ring.

three wideband RF channels for each plane and performs the amplitude (transverse FB) and the phase demodulation (longitudinal FB) via RF mixing with the third harmonic of the ELSA RF clock, in order to get baseband signals which are proportional to the phase/position displacement.

Digital Signal Processing

Each channel of the front-end is connected to one DSP unit (Dimtel iGp12-274F) which is mainly realized as a field programmable gate array (FPGA) platform. The signals are digitized by using a 12-bit ADC, triggered by the ELSA RF clock provided also by the front-end. Each of the 274 bunches is processed in a digital finite impulse response (FIR) filter with up to 32 taps in order to determine a correction signal which is then passed to a 12-bit DAC after an adjustable output-delay. The required timing (ADC and DAC delay in ps range and the output delay in units of the RF period), the filter generation (phase and frequency), the adjustment of the front-end (local oscillator mixer phases) as well as data acquisition and control of the complete system is performed via the EPICS software. Further details of iGp12-274F can be found in [5].

Amplifiers & Kickers

After the up-conversion to 1 GHz in the back-end, the longitudinal correction signal drives via a broadband 200 W amplifier (Milmega AS 0102-200) the 4 RF inputs of an already installed, in-house developed prototype of a low-Q pillbox kicker cavity [6]. For each transverse plane, we use a 100 W amplifier (Amplifier Research 100A250A) and a broadband 180° splitter to drive an existing kicker with horizontal and vertical striplines. A new stripline kicker with a larger bandwidth is currently in fabrication [7].

COMMISSIONING

In order to close the FB loops, we operated the stretcher-ring in the storage mode at constant energy. Since the single-bunch injection is currently still under construction, two-fifths of the buckets of the stretcher ring were filled. The front-end phase shifters were adjusted for demodulation as well as the ADC delays for accurate sampling of the displacement signals of each bunch. Using the internal frequency generator (DC - 250 MHz) of the iGp modules, one bunch is excited at the synchrotron or the betatron oscillation frequency. By observing the response of the same bunch, the output delay, the DAC delay and—in case of the longitudinal FB—the back-end carrier phase was optimized in terms of isolation between neighbouring bunches. Finally, the phase of the FIR bandpass filter located at the synchrotron or the betatron frequency was adjusted to obtain an at most pure resistive damping performance of the system.

In Fig. 2 a typical drive-damp measurement during the commissioning of the longitudinal FB at 2.35 GeV and a beam current of 10 mA is presented. These turn-by-turn

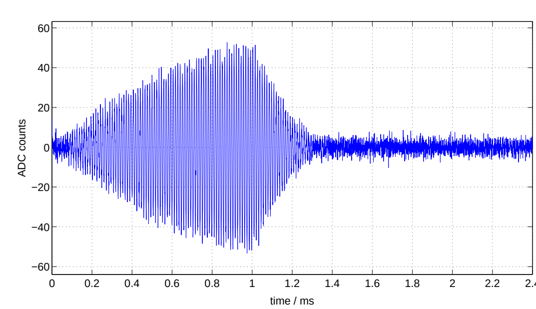

Figure 2: Drive-damp measurement: ADC-data of one bunch recorded turn-by-turn using the longitudinal FB system.

data are recorded via the ADC by the longitudinal iGp module and show the time-dependent phase displacement signals of the bunch with the largest oscillation amplitude. In the range of 0 - 1 ms, the phase of the bandpass filter was shifted by $180°$ in order to excite synchrotron oscillations of the bunches. At 1 ms, the filter coefficients are set back and the FB damping performance is clearly visible. The Fourier spectrum of the ADC-data averaged over all filled buckets is illustrated in Fig. 3. The red spectrum corre-

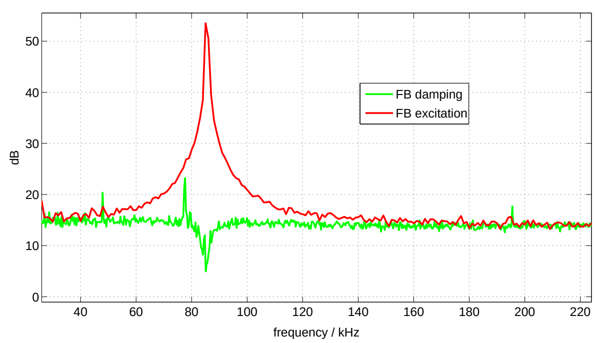

Figure 3: Synchrotron frequency peak and its suppression in the Fourier spectra computed from the presented drive(red)-damp(green) measurement. The additional narrow peaks are also visible without beam and are caused by noise.

sponds to the data recorded during the 1 ms drive phase of the FB and results in a synchrotron oscillation frequency f_s of 85.5 kHz. The green spectrum whose data was recorded during the damp phase is characterized by a notch at f_s and indicates the successful operation of the longitudinal FB.

Fast Energy Ramp

For the operation of the FB systems in the standard booster mode of the stretcher ring with an energy ramp of 4 GeV/s, it is necessary that the shift of bunches' synchronous phase $\varphi_{\rm syn}$ during the ramp stays within an acceptable range which still allows a proper amplitude and phase demodulation of the bunch signals in the front-end. Furthermore, for the computation of the correction signals by the bandpass filtering of the longitudinal FB the synchrotron frequency f_s should be nearly constant.

These requirements can be fulfilled by a linear ramp of the total cavity voltage. In case of an energy ramp of 1.2 GeV to 2.35 GeV, this results in voltage ramping of 1.0 MV to 1.9 MV, an almost constant f_s and an acceptable shift of $\varphi_{\rm syn}$ of $6.6°$ (see Fig. 4). Fast longitudinal tune measurements during the linear ramp of the cavity voltage confirm that the synchrotron frequency can be stabilized at (86.0 ± 1.5) kHz [8].

Results

The longitudinal FB system is working successfully in the ELSA booster mode with a fast energy ramp of 1.2 GeV

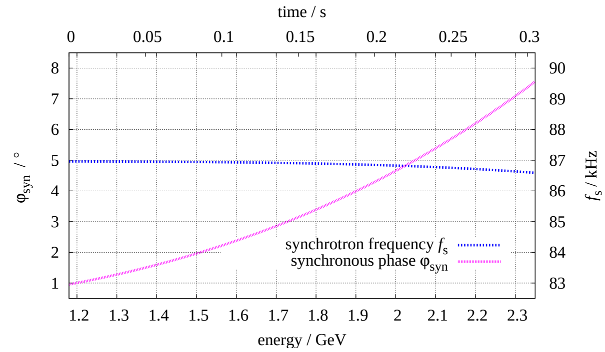

Figure 4: Development of $\varphi_{\rm syn}$ and f_s during the energy ramp, calculated for a linear ramp of the cavity voltage.

to 2.35 GeV and internal beam currents of up to 30 mA. By operating the longitudinal FB, the injection efficiency in the stretcher ring could be improved, lower beam losses during the ramp were achieved and also the intensity variation of external beam current was reduced significantly. Furthermore, the horizontal FB loop could already be closed and the horizontal system is ready for commissioning during the booster mode.

OUTLOOK

In the near future, we will complete the operation of the booster mode with FB systems in all three planes at the stretcher ring. Using this setup, we aim for the acceleration of beam currents as high as possible as well as for a detailed determination of the types and modes of the excited beam instabilities. Additionally, we will install a temperature stabilization system for the cooling circuit of the PETRA cavities in order to reduce the influence of the harmful HOM on the excitation of instabilities.

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