BROAD AND NARROW BAND FEEDBACK SYSTEMS AT ELSA*

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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 6 GeV/s from 1.2 GeV to 3.5 GeV. The intended upgrade is mainly limited due to the excitation of multi-bunch instabilities. As a countermeasure, we succesfully commissioned state-of-the-art bunch-by-bunch feedback systems in the longitudinal and the two transverse dimensions. In addition, a narrow band cavity based feedback system for damping the most harmful longitudinal multi-bunch mode caused by a HOM of the accelerating cavities is under construction.

ELECTRON STRETCHER ACCELERATOR – ELSA

At the Electron Stretcher Accelerator ELSA spin polarized [1] or unpolarized electrons are injected into the fast ramping booster synchrotron at $20\,\mathrm{MeV}$ using one of the two linear accelerators. After extraction at a beam energy of $1.2\,\mathrm{GeV}$, the electrons are accumulated in the ELSA storage ring. Here, a further acceleration up to $3.5\,\mathrm{GeV}$ with a ramping speed of $6\,{}^{\mathrm{GeV}}/_{\mathrm{s}}$ can be applied. Using resonance extraction methods it follows an extraction phase of about $4\,\mathrm{s}$ to the hadron physics experiments [2].

Upgrading the operation of the stretcher ring from typical beam currents of $20\,\mathrm{mA}$ to $200\,\mathrm{mA}$ requires a multitude of enhancements to reduce the excitation of multi-bunch instabilities.

EFFECTS EXCITING MULTI-BUNCH INSTABILITIES

For beam currents up to $100\,\mathrm{mA}$ multi-bunch instabilities at ELSA are mainly dominated in the longitudinal phase space. In particular, the two five-cell PETRA cavities used for particle acceleration feature some higher order modes (HOMs) with large longitudinal shunt impedance. If one of the beam's synchrotron sidebands overlaps with the resonance frequency of such a HOM, the beam starts to oscillate coherently building up a multi-bunch instability. The latter only occurs if the excitation rate is larger than the natural damping of the beam caused by synchrotron radiation. The resulting HOM spectrum including the natural damping threshold is shown in Fig. 1 which has been calculated for a circulating beam current of $100\,\mathrm{mA}$.

Especially the HOM at $1.46\,\mathrm{GHz}$ is causing longitudinal excitation by driving the lower synchrotron sideband of the 21th revolution harmonic. With the harmonic number being 274, this excites the multi-bunch mode 253.

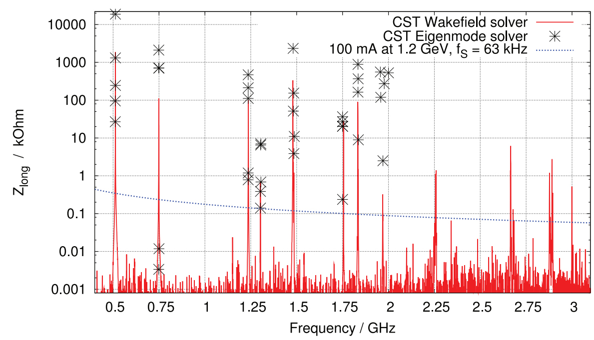

Figure 1: Wake impedance and natural damping calculations [3] of a five-cell PETRA cavity using CST Microwave Studio™.

MULTI-BUNCH FEEDBACK SYSTEM AT ELSA

In order to damp the multi-bunch oscillations excited in the longitudinal and transverse planes, a state-of-the-art bunch-by-bunch feedback system is in operation, consisting of four major parts.

A beam position monitor (BPM) picks up a signal corresponding to the bunch's position. Then, the frontend of the feedback system mixes the BPM signal with the third harmonic of the ELSA $500\,\mathrm{MHz}$ master RF to isolate a signal only including information about the beam oscillations. By amplitude or phase demodulation the requested properties can be obtained. Using phase demodulation, the longitudinal position of every single bunch can be extracted. Amplitude demodulation allows for measuring the transverse position. A fast ADC converts the signals into digital format. Using an FPGA [4], a digital filter with a maximum of 32 taps insulates the oscillation frequency of every single bunch, allowing to generate a correction signal which is sent to a fast DAC. The resulting correction signal requires broadband processing, reaching from DC to a maximum of $250\,\mathrm{MHz}$, which is half of the accelerating RF. In the transverse planes, two broadband RF amplifiers in use ensure a sufficient RF power for a proper damping of every single

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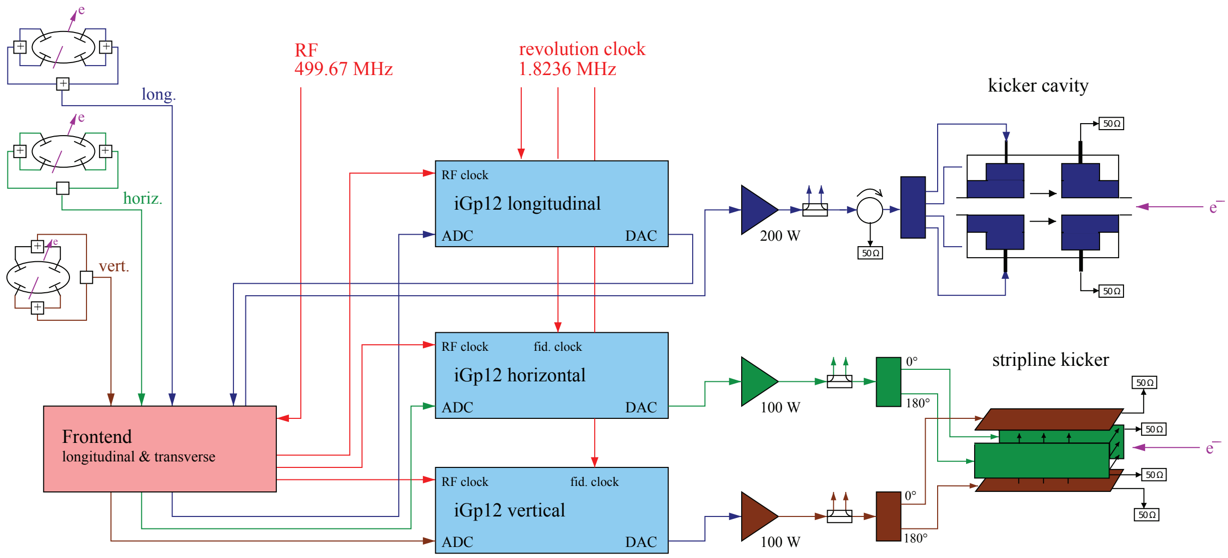

Figure 2: Overview of the bunch-by-bunch feedback system at ELSA [3].

bunch in the connected stripline kicker. In the longitudinal plane, the attached kicker cavity operates at $1 - 1.25\,\mathrm{GHz}$, which requires a mixing of the correction signal with the second RF harmonic before amplification. An overview of the feedback system including all major components is given in Fig. 2.

The transverse stripline kicker consists out of four striplines in order to provide horizontal and vertical correction. The longitudinal kicker cavity is optimized to a loaded quality factor of 4.5 to assure the required bandwidth of $250\,\mathrm{MHz}$. Both, stripline kicker [5] and kicker cavity [6] are in-house developments adjusted to the ELSA RF frequency and bunch length.

MEASURING MULTI-BUNCH INSTABILITIES AT ELSA

The bunch-by-bunch feedback system allows for measuring the three dimensional position of every single bunch. Using this data for further analysis enables a better understanding of the beam's behaviour.

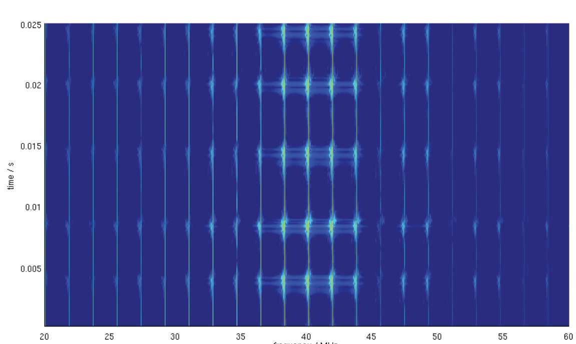

Figure 3: Waterfall plot of the beam spectrum.

The maximum acquisition length is limited to 45921 revolutions, leading to a maximum acquisition time of about $25\,\mathrm{ms}$. The data is represented in a two-dimensional matrix of size 274×45921 which allows to analyze subsets in time and bunch patterns. It can be used to plot the time dependent bunch motion and spectrum, like shown in Fig. 3 and 4.

In this example, the filling pattern of the stretcher ring was set to only fill $1/7$th of the buckets with a beam current of $42\,\mathrm{mA}$ and $2.0\,\mathrm{GeV}$ end energy. From the acquired data it is possible to derive the beam's oscillation frequency, which in this case is the synchrotron frequency, as well as the phase advance per bunch, which automatically determines the multi-bunch mode number of the coherent oscillation.

In this example, the coherent multi-bunch oscillation shown in Fig. 4 corresponds to the longitudinal mode 253 which is driven by the PETRA HOM at a frequency of $1.46\,\mathrm{GHz}$ when switching off the broadband feedback system. In base band, this oscillation results in a longitudinal BPM signal at $40\,\mathrm{MHz}$ which is the lower sideband of the 21th revolution harmonic. Figure 3 shows the time dependent spectrum of the longitudinal bunch motion. Here, the maximum oscillation amplitude at $40\,\mathrm{MHz}$ varies in time due to unstable excitation processes.

Regarding these longitudinal motions requires an additional damping for this multi-bunch mode in order to obtain the proposed beam currents.

NARROW BAND FEEDBACK SYSTEM AT ELSA

In order to assure a proper damping of the longitudinal multi-bunch mode 253 even at high beam currents a narrow band feedback is required, in addition to the broadband feedback sytem. A diagnostic loop of one of the two PETRA cavities is used to couple out a signal proportional to

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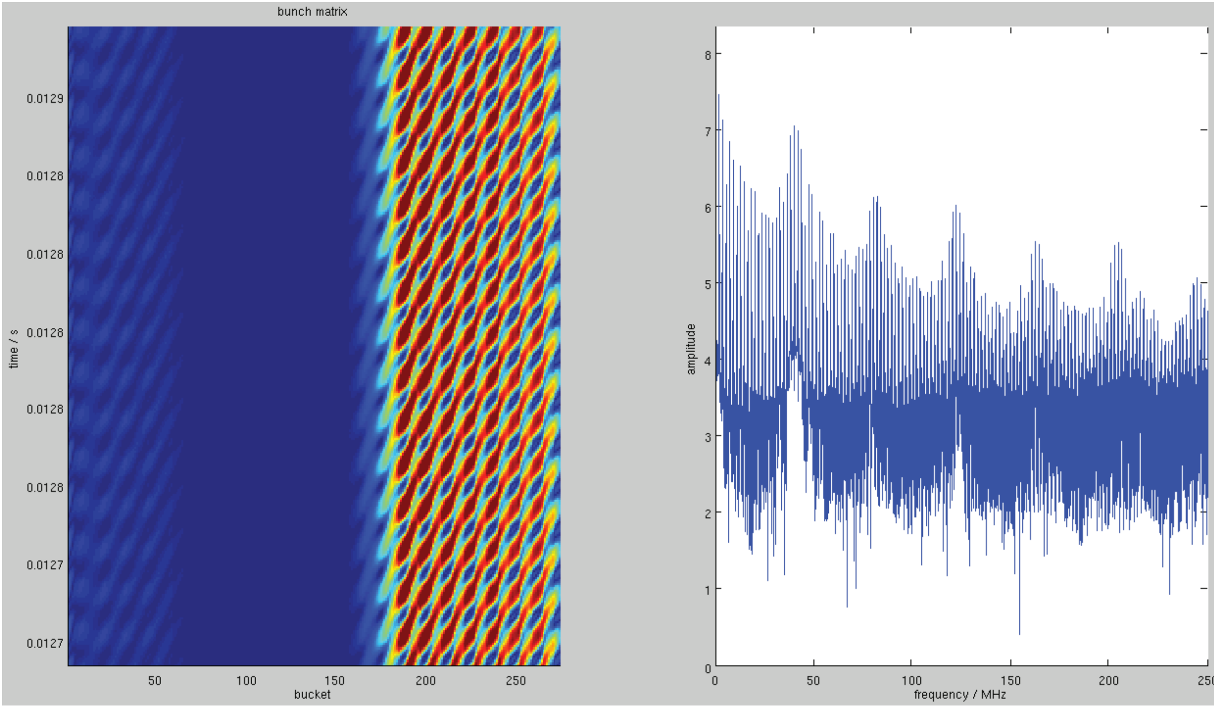

Figure 4: Time evolution and spectrum of the longitudinal phase space.

the driving HOM of mode 253. Adding a band pass filter at the HOM's frequency and a phase shifter to achieve a signal shifted by 90 degrees allows for driving a narrow band high Q cavity optimized for the HOM's frequency of 1.46 GHz.

The required cavity is shown in Fig. 5, equipped with two tuners to adjust the cavity's resonance frequency. Its RF properties are summarized in Table 1.

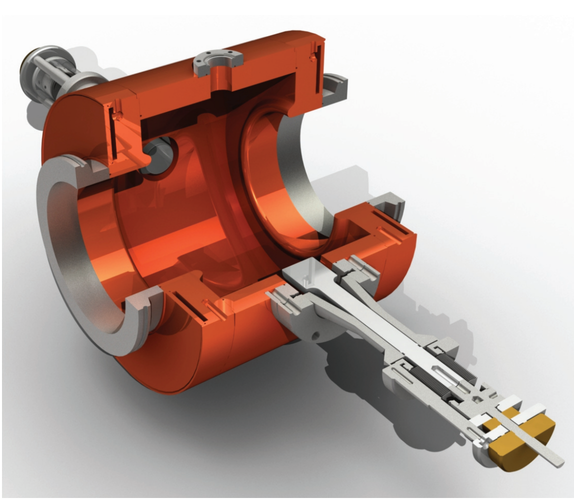

Figure 5: Cavity for narrow band feedback system optimized to the frequency of mode 253 being 1.46 GHz.

Table 1: Properties of the narrow band feedback cavity calculated with CST Microwave Studio™

frequency	**quality factor**	**shunt impedance**
1.459 GHz	29 260	18.6 MΩ

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