

# BUNCH-BY-BUNCH FEEDBACK SYSTEMS AT THE DELTA STORAGE RING\*

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## Abstract

At the DELTA 1.5-GeV electron storage ring operated as a synchrotron radiation source by the TU Dortmund University, bunch-by-bunch feedback systems have been recently installed and commissioned to detect and suppress longitudinal as well as transverse multibunch instabilities. Besides that, the feedback systems are used as a diagnostics tool. Growth rates of multibunch instabilities and their dependence on the beam current have been measured. Additionally, the oscillation amplitudes of electron bunches have been studied during the injection process.

a two-cycle comb filter and are mixed with a multiple of the RF frequency. Remote-controllable phase shifters and attenuators allow to set the phase-sensitive (longitudinal) and amplitude-sensitive (transverse) detection mode. After passing a low-pass filter, the analog signals are digitized using 12-bit analog-digital converters. Each processing unit uses a 32-tap FIR (finite impulse response) filter to compute a correction signal which is converted to an analog signal and sent to a power amplifier driving the kicker structure (Fig. 2). Both transverse feedback systems employ a common stripline kicker [4]. For each axis, only one electrode is connected and the opposite electrode is kept floating. For the longitudinal case, a strongly damped kicker cavity is used, employed to obtain the necessary bandwidth of 250 MHz [4].

## INTRODUCTION

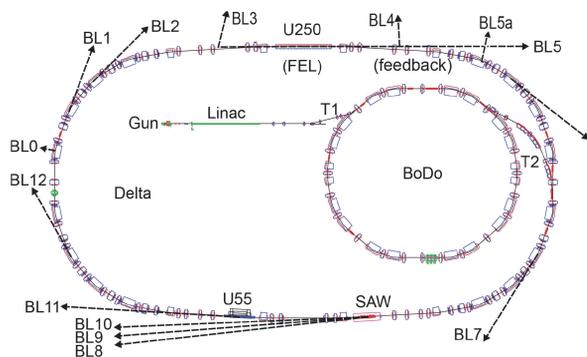


Figure 1: Overview of the DELTA facility.

At the 1.5-GeV synchrotron radiation source DELTA operated by the TU Dortmund University, multibunch instabilities occur at a current threshold around 70 mA. The typical fill pattern comprises  $\approx 140$  bunches in 192 RF buckets. To investigate and suppress multibunch instabilities, bunch-by-bunch feedback systems and the respective kicker structures were installed in 2011 in the northern part of the storage ring (Fig. 1). So far, the feedback systems are in use during coherent harmonic generation (CHG) experiments [1, 2] to improve the laser-electron interaction and to perform beam studies in dedicated machine shifts. In standard user shifts, an RF phase modulation increases the beam lifetime precluding the use of the feedback system. To detect the longitudinal and transverse position of electron bunches, a beam position monitor (BPM) is used. A hybrid network provides the differential signals  $\Delta x$  and  $\Delta y$  as well as the sum signals for the feedback frontend [3], in which the analog signals pass

Table 1: specific parameters

parameter	value
revolution frequency	2.6 MHz
RF frequency	500 MHz
nominal RF power	25 kW
nominal beam current (multibunch)	130 mA
nominal beam current (single bunch)	15 mA
synchrotron frequency	14.7 kHz
horizontal betatron frequency	260 kHz
vertical betatron frequency	740 kHz
kicker cavity central frequency	1274 MHz
kicker cavity quality factor	5.5
amplifier power (longitudinal)	200 W
amplifier power (transverse)	150 W
overall bandwidth	250 MHz

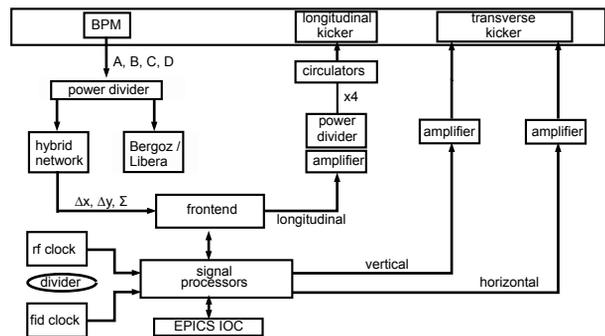


Figure 2: Overview of the feedback systems.

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## ABSOLUTE CALIBRATION

### Longitudinal Feedback System

The calibration of the longitudinal feedback unit was performed in the linear region of the phase-sensitive detection mode (inset of Fig. 3). When the RF power is reduced, the synchronous phase  $\phi_s$  changes. To calibrate the phase detector signal ( $\sim I\Delta\phi_s$ ), the position of the electron bunches in terms of the RF phase was determined using a laser-induced THz signal. Here, a short laser pulse interacts with a slice of an electron bunch, which gives rise to coherent THz radiation proportional to the number of electrons squared in the interaction area. By changing the delay of the incoupled laser pulse, the longitudinal position of the bunch centroid was determined [5]. Fig. 3 displays the feedback signal to be calibrated under variation of the synchronous phase (in time units). The negative slope of the linear fit is due to the chosen reference phase as shown in the inset of Fig. 3.

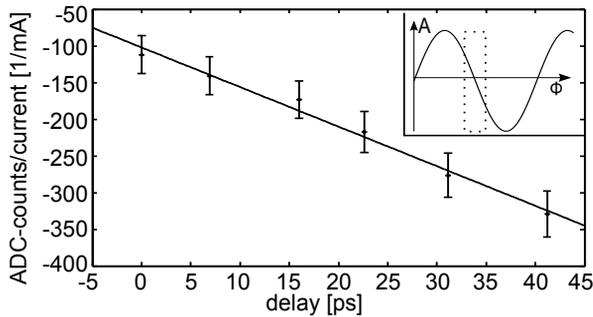


Figure 3: Correlation between the feedback signal and the longitudinal position of the electron bunches. The error bars indicate the standard deviation of the ADC counts acquired over 25 ms. The inset shows the phase-sensitive region of the reference phase.

### Transverse Feedback Systems

To calibrate the transverse feedback units, the electron orbit was shifted at the position of the BPM used by the feedback systems. In the amplitude-sensitive detection mode, the transverse signal recorded by the feedback system is proportional to  $I \cdot y$  with the bunch current  $I$  and the oscillation amplitude  $y$ . This was compared to the absolute position, determined using Bergoz readout electronics additionally connected to the BPM. Figure 4 shows the resulting correlation between the feedback signal and the BPM data for the horizontal and vertical plane.

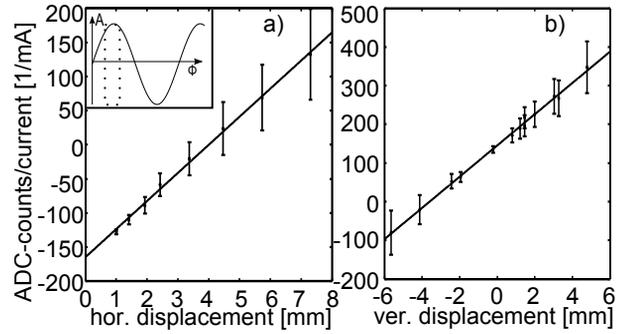


Figure 4: Absolute calibration of the horizontal (a) and vertical (b) feedback system. The inset shows the amplitude-sensitive region of the reference phase.

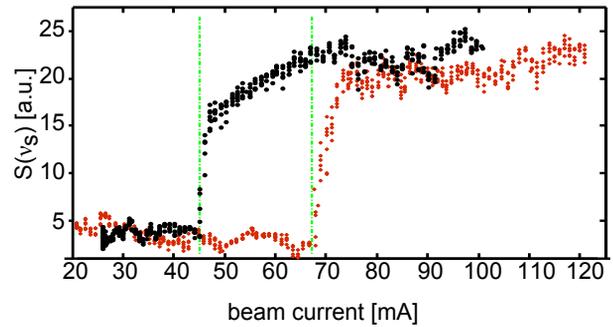


Figure 5: Spectral component at the synchrotron frequency taken from the single-bunch spectrum for different beam currents with the superconducting wiggler switched on (red) and off (black).

### Grow-Damp Measurements

In order to investigate the growth rates of longitudinal multibunch instabilities and to determine which modes are excited at DELTA, grow-damp measurements were performed. Figure 6a displays a grow-damp measurement taken at a beam current above the instability threshold. The feedback system damps the instabilities until it is disabled at time  $t = 5$  ms. After additional 5 ms, the feedback system is re-enabled. Fig. 6b shows the calculated mode spectrum dominated by the longitudinal multibunch mode 12.

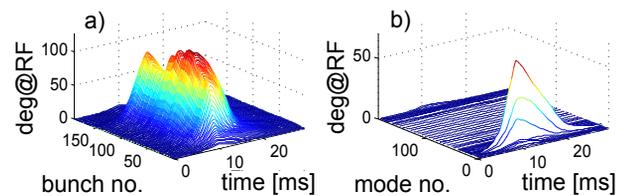


Figure 6: Grow-damp measurement in time domain (a) and the corresponding mode spectrum (b).

## MULTIBUNCH INSTABILITIES

### Instability Thresholds

At the DELTA storage ring, multibunch instabilities are observed at a beam current above typically 70 mA when the superconducting 5.3-T wiggler is in operation. Switching the wiggler off lowers the instability threshold to about 45 mA due to reduced radiation damping (Fig. 5).

In Fig. 7, the growth rate of mode 12 is displayed for different beam currents with the superconducting wiggler switched off. A linear fit yields

$$\tau^{-1} = (4.9 \pm 0.2) \cdot 10^{-3} \frac{I}{\text{ms} \cdot \text{mA}} - (0.246 \pm 0.023) \frac{1}{\text{ms}}.$$

The intercept at zero current corresponds to the radiation damping rate  $1/\tau_s$ . The value is consistent with

$$\frac{1}{\tau_s} \approx \frac{V_s f_0}{E} \approx 0.233 \frac{1}{\text{ms}} \quad (1)$$

with the energy loss per revolution  $V_s \approx 135$  keV, the beam energy  $E$ , and the revolution frequency  $f_0$ .

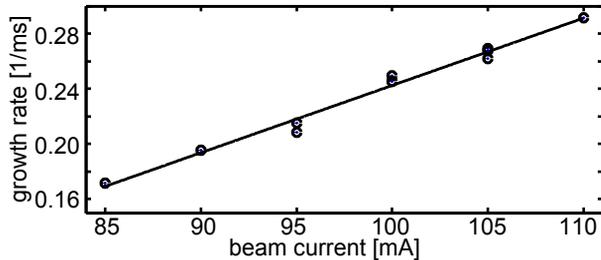


Figure 7: Growth rate of multibunch mode 12 as function of the beam current.

### Active Drive

Besides using the feedback systems, to damp instabilities they can be used to actively drive stable modes. By moving the driving frequency periodically (frequency span 15 kHz, period time of 200  $\mu\text{s}$ ) over the vertical betatron oscillation frequency it was possible to kick out single bunches in a multibunch filling pattern using the vertical kicker.

## INJECTION STUDIES

The data acquisition of the feedback systems can be triggered by an external event. One example is the injection of bunches into a storage ring [6]. At DELTA, three injection kickers are used to change the orbit during injection causing a transverse excitation of all stored electron bunches due to a not perfectly closed kicker bump. The horizontal feedback system was used to record the oscillation amplitudes of all bunches over 4500 turns after injection (Fig. 8a). Figure 8b shows the oscillation amplitude of bunch 95 as an example. The spectra obtained by FFT at different time intervalls over 400 revolutions are shown in Fig. 8c. Shortly after injection, a frequency slightly lower than the horizontal betatron frequency dominates. After about 500 revolutions, the horizontal oscillation amplitude is strongly reduced and reoccurs after about 1000 revolutions at the nominal betatron frequency and its second harmonic until it finally vanishes. Due to dispersion at the BPM position a signal at the synchrotron frequency with constant amplitude is also visible. As shown in Fig 8a, the phase of the synchrotron oscillation corresponds to mode number

$$\mu = \frac{h \cdot \Delta\Phi_n}{2\pi \cdot n} \approx 12, \quad (2)$$

where  $h$  is the harmonic number and  $\Delta\Phi_n/n$  is the phase difference between two adjacent bunches.

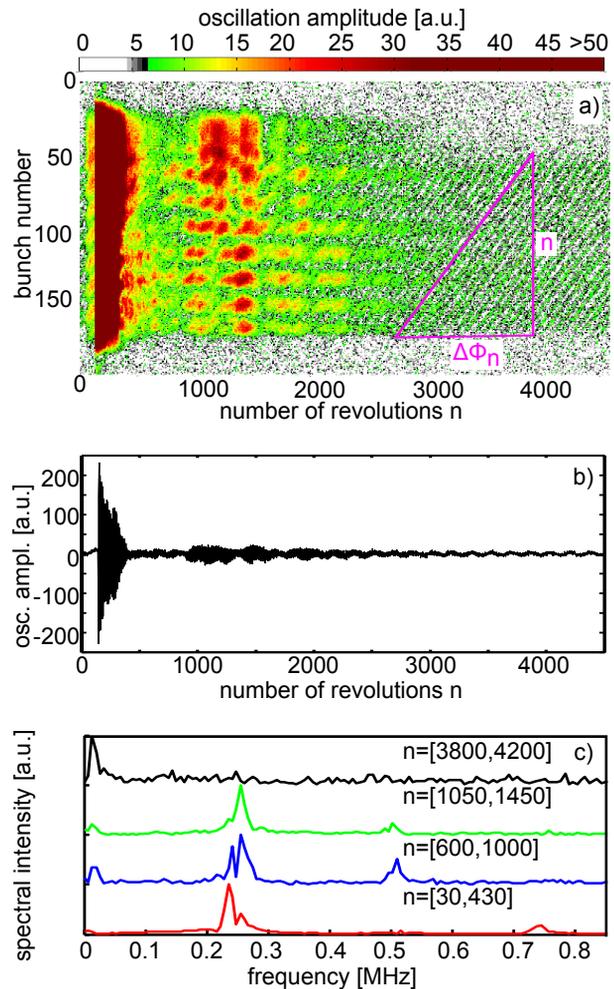


Figure 8: Oscillation amplitudes of all bunches (a) and of bunch 95 (b) for 4500 revolutions after injection. Also shown are spectra at different time intervalls after injection (c), normalized to the respective maximum.

## ACKNOWLEDGEMENT

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