# FIRST RESULTS OF THE NEW BUNCH-BY-BUNCH FEEDBACK SYSTEM AT ANKA

E. Hertle, N. Hiller, E. Huttel, B. Kehrer, A.-S. Müller,
N. J. Smale, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
M. Höner, Center for Synchrotron Radiation (DELTA), Dortmund, Germany
D. Teytelman, Dimtel, Inc, San Jose, USA

*Abstract*

A new digital three dimensional fast bunch-by-bunch feedback system has been installed and commissioned at ANKA. Immediate improvements to stored current and lifetime were achieved for normal user operation. For this, the feedback has to be running during the injection and the energy ramp to 2.5 GeV. Additionally, the feedback system was also incorporated into the diagnostic tool-set at ANKA and opened up new possibilities of automated and continuous measurement of certain beam parameters. The system can operate in different modes such as the low alpha operation mode, which has different requirements on the feedback system compared to normal user operation. Results on the various aspects will be presented as well as future improvements.

## INTRODUCTION

ANKA at the Karlsruhe Institute of Technology is a 2.5 GeV synchrotron light source with a circumference of 110.4 m and a RF frequency of $f_{\mathrm{RF}} = 500\,\mathrm{MHz}$. The injection process is performed at 0.5 GeV. For standard user operation the accumulation period lasts 30 to 45 minutes, whereafter the beam energy is increased to 2.5 GeV during a slow energy ramp lasting four minutes. The storage ring is filled twice a day. For a limited time per month, ANKA operates at varying energies during special user operation, mostly at 1.3 GeV in the so-called low-$\alpha_c$ mode to study coherent THz radiation [1]. Whereas the filling structure for standard user operation aims to be homogeneous to get a high integrated beam current and long lifetimes, the demands for special user operation vary depending on the measurements and may go down to a single bunch and very low bunch currents.

## IMPLEMENTATION

In October 2013 a new digital FPGA-based three dimensional bunch-by-bunch feedback system has been implemented at ANKA. We decided on a commercially available solution provided by Dimtel, Inc. This system is in use by various other synchrotron light sources in Germany and across the globe. A pick-up signal is provided by one of our beam position monitor buttons. A single front/back end unit combines the initial signal processing from the pick-up and the distribution to the so called iGp units (Integrated Gigasample Processors) for each plane as well as the back-end up-conversion and sets adjustable phase shifter for gain and timing calibration [2]. The feedback system allows real-time signal processing for all of the maximum 184 bunches at ANKA. More technical details on the hardware can be found in [3]. For transverse feedback, a horizontal and vertical stripline kicker is used. Each stripline is powered by a 150 W, 250 MHz amplifier manufactured by Barthel [4]. A second additional stripline would be available for each plane for possible differential feedback, if the need for that arises. A significant requirement to improve operation at ANKA is to ensure a running feedback system during the injection process and the slow energy ramp. Beam synchronous phase changes by more than 30 degrees (90 degrees at detection frequency) during the energy ramp. To maintain negative feedback in transverse planes, front-end local oscillator signals were made to track the longitudinal phase servo loop.

## IMPACT & RESULTS

We achieved immediate improvements to the operation of the ANKA storage ring since the implementation of the feedback system. The following subsections list the most significant ones.

### *For User Operation*

Before the installation of the feedback system, we were limited to operate with 100 out of 184 possible bunches, separated by gaps into three bunch trains. This was necessary to ensure the stability during the injection and energy ramp. Now we are able to inject a fourth train and reduce the gaps between the trains, leaving only one noticeable gap after the fourth train. Therefore we can operate at lower bunch currents for the same integrated beam current leading to a significant increase in lifetime. For each fill we compare the lifetime at the same current level during the decay over the fill. Comparing the lifetime at 130 mA, we observed an increase by 25%. Additionally, we are now also able to increase the overall accumulated current from 165 mA, for the most of 2013, to an average of 195 mA per injection. With these improvements in mind, we are looking at possible options to change the duty cycle at ANKA. One option would be to accumulate more than 200 mA and only do a single injection per 24 hours. This would allow for one more hour of beam time and less interruptions at the beamlines. We already managed to inject and ramp well above the targeted current level during machine studies.

### *For Machine Studies*

Apart from the improvements for standard user operation, the feedback system provides useful additions to the diag-


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nostic tool-set at ANKA. For example, we are now able to monitor our betatron- and synchrotron frequencies continuously in our control system. This does not only help the operators, but logs of these values are now added to our database. Furthermore this improves various other measurements which depend on the tune values. One example is shown in Fig. 1, where multiple chromaticity scans have been performed fully automated. Mean values for two different cases regarding the state of one of our insertion devices. These measurements show the precision of the tune readout, as the statistical errors are significantly smaller than the difference due to the tune shift induced by the insertion device. Table 1 shows the result for the linear and quadratic terms of the measured horizontal chromaticity at 2.5 GeV. Moreover, due to the possibility to perform controlled grow-damp measurements, additional investigations are now possible. Eigenmode and bunch train coupling studies are a prime example [5]. Figure 2 shows the measured longitudinal eigenmodes appearing during the injection and ramping process where we do not have active longitudinal feedback as of now.

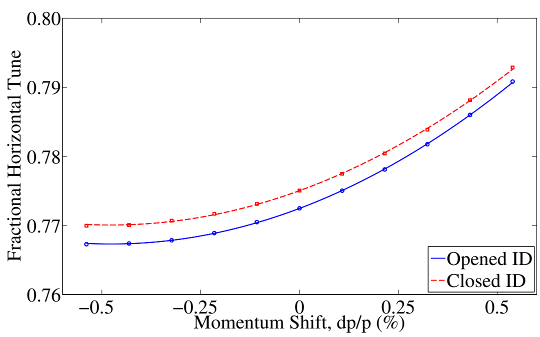


Figure 1: Results of multiple automated chromaticity scans enabled by the fully integrated tune readout. The blue curve represents the mean data of the scan with all insertion devices opened, whereas the red curve is the result with one insertion device closed. The statistical errors on the measured values are smaller than the size of the markers for each data point, demonstrating that changes to the machine state create tune shifts clearly resolved by the tune measurement method.

Table 1: Results of Horizontal Chromaticity Measurements

| **Insertion Device** | $Q'_x$ | $Q''_x$ |
|---|---|---|
| opened | 2.161 ± 0.003 | 226 ± 2 |
| closed | 2.084 ± 0.004 | 218 ± 4 |

### *For Special User Operation*

Since the implementation of the feedback system, there has been a high demand to improve various measurements in our low-$\alpha_c$ operation. It does provide easily accessible important beam parameters such as the synchrotron frequency, as already mentioned before, but also a quick estimation

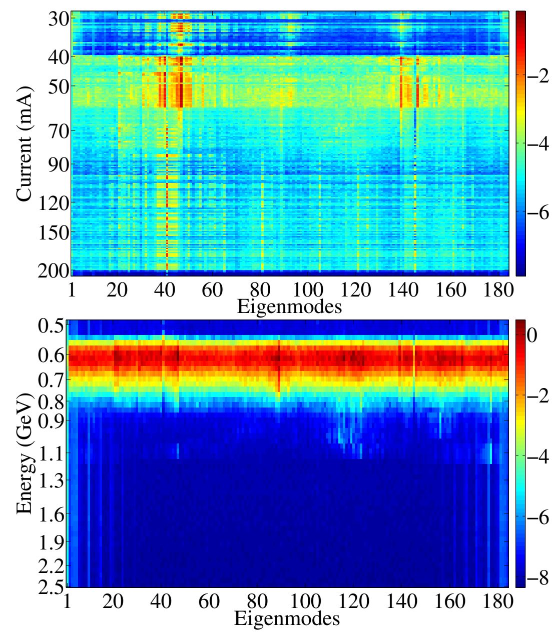


Figure 2: Longitudinal stability of the beam during injection and ramping process. Throughout the injection every 5 seconds a measurement of bunch motion was recorded for every bunch for consecutive 65 thousand turns. Analysis of the raw data extracts mean amplitudes of coupled-bunch eigenmodes, plotted in horizonal lines. Both plots use a equidistant vertical axis since neither the injection rate nor the energy ramping speed is linear over time. The top plot shows the injection process up to 210 mA. Noticeable is the the region between 40 mA and 60 mA, where a change-over for the most prominent mode is happening. The major contribution to these eigenmodes seem to be induced by the injection kicks needed to accumulate the current since the height of all modes drastically decreases once the injection process is stopped as seen for the last few values. Directly after the injection is stopped, the energy ramp starts in the bottom plot showing very strong instabilities below 1 GeV and the disappearance of most modes at 1.3 GeV and above.

of individual bunch currents. A core feature is the possibility to excite single bunches. One extreme application is the possibility to remove all bunches except one during the injection process. Comparing the single bunch cleaned from a whole train to previous measurements in our standard single bunch injection [6] shows at least the same level of purity. The advantage comes into play as soon as we want to inject a second single bunch, for example for studies with two consecutive bunches. Injecting a whole train of bunches and reducing the train pattern down to the wanted number of bunches is much faster than injecting every single bunch on its own. Additionally, we are now able to use our standard user operation injection setup also for single bunch injections. This reduces the time needed for optimising the single bunch injection, which is used rarely compared to the standard user operation settings. Figure 3 shows such a pseudo-single bunch injection during the injection process and after the final cleaning measured by our time correlated single photon counting system [7]. We are at the moment in the process of improving the photon counting measurement, for example to remove the long tail, but the results already hint at a single bunch purity of at least $10^4$. A closely related

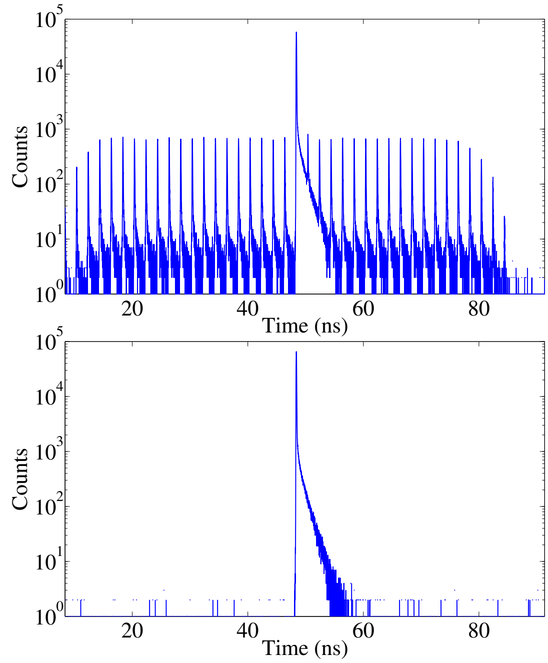


Figure 3: Pseudo-single bunch injection with the help of the feedback system. Instead of only injecting a single bunch, a whole bunch train is injected and at the same time all bunches except one are highly excited and, therefore, suppressed. The purity is measured with time correlated single photon counting (see text). During the injection, the whole train is still visible as shown in the top plot. Once the injection is stopped the remaining unwanted bunches are cleaned out as seen in the bottom plot.

application is the possibility to reduce individual bunch currents to desired values and therefore create arbitrary filling patterns. One example of such a filling pattern is shown in Fig. 4, which started off as a four train fill. This allows not only to study the effect of bunch-bunch interactions, but also a much faster method of investigating the so-called bursting threshold in a one second measurement. For this, we have to take care that roughly half of the bunches are below and half of the bunches above the bursting threshold. We achieve this by creating a linear slope of bunch currents. For measuring the behavior of every bunch on every turn for one second, a newly designed acquisition board, called KAPTURE is used. More details about the bursting behavior and KAPTURE can be found in [8].

## CONCLUSION AND OUTLOOK

As shown in this overview paper about the first results of the new feedback system at ANKA, we were able to achieve improvements in many aspects. Stability and lifetime for

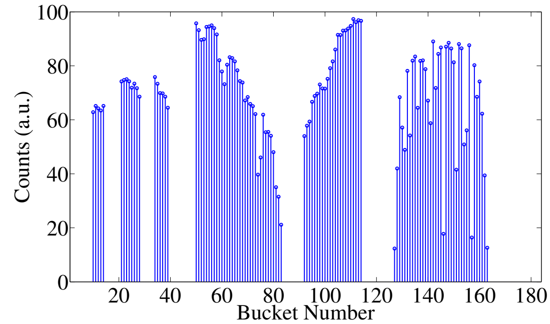


Figure 4: Tailored filling pattern. This data was taken with the online bunch current monitor provided by the feedback system. The x-axis shows the bucket numbering with all possible 184 buckets at ANKA. The y axis is in arbitrary counts used as relative bunch currents. After a regular four train injection this filling pattern was created on purpose. The first train is separated into smaller trains, the second and third train represent a positive and negative bunch current slope over the length of the train. The fourth train represents various bunch currents distributed randomly throughout the train.

standard user operation, better diagnostics for machine studies and new applications for special user operation. Further machine studies are being carried out at the moment. For standard user operation we have some more ideas of increasing the beam lifetime and current. The limiting factor here is the missing longitudinal feedback, since for high currents we have to decrease the strength of our transverse feedback due to strong longitudinal oscillations. The possibility to damp or excite longitudinal motion is also of interest for our special user operation. The needed longitudinal kicker cavity has now been ordered and is scheduled to be installed into the storage ring as soon as possible.

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