

BEAM STUDIES WITH THE NEW LONGITUDINAL FEEDBACK SYSTEM AT THE ANKA STORAGE RING

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Abstract

With the now fully commissioned longitudinal feedback system at the ANKA Storage Ring - in addition to the already operational transverse feedback system - the stability throughout the injection process was increased considerably. This opened up the possibility of being able to investigate beam dynamics and limitations during injection more systematically. This paper presents the results of these studies, an overview of the limiting parameters, and discusses possible approaches to increase the efficiency of the injection.

INTRODUCTION

ANKA is a 2.5 GeV synchrotron light source located at the Karlsruhe Institute of Technology, Germany. The circumference of the ring is 110.4 m and operates with a RF frequency of 500 MHz. Injection into the storage ring happens at 0.5 GeV, where the beam current is accumulated during a 1 Hz injection cycle for 30 to 60 minutes twice a day up to 200 mA. After the accumulation process the energy of the beam is increased slowly over 4 minutes to the final energy. During special measurement shifts the storage ring is also operating at lower energies, mainly 1.3 GeV. In these shifts a special optics is used to reduce the bunch length as much as possible to study the generation of coherent THz radiation [1]. During this so-called low α_c mode the emphasis is not on overall high beam currents, but more on special filling patterns [2].

Table 1: ANKA Parameters

Parameter	Value
Energy	0.5 GeV - 2.5 GeV
Circumference	110.4 m
RF Frequency	500 MHz
Harmonic Number	184
Beam currents	0.1 mA - 200 mA
Synchrotron Frequency	4 kHz - 40 kHz

STATUS OF FEEDBACK SYSTEM

A digital bunch-by-bunch feedback system is in operation at ANKA since October 2013. In the initial setup active feedback was only used in both transverse planes using stripline kickers to damp coherent betatron oscillations. Significant improvements to the operation of the storage ring were achieved by active damping of coupled bunch instabilities allowing to increase the number of filled buckets. This increased Touschek lifetime for similar total beam current

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considerably. Additionally, machine development profited by the improved diagnostic capabilities such as continuous tune measurements and analyzes of beam instabilities. Finally also operation in the low- α_c mode improved with the possibility of active bunch cleaning to influence the filling pattern [3]. Overall, the feedback system became an essential part of beam operations in all operation modes. Although active longitudinal feedback was not possible in the beginning due to a missing effective kicker for the longitudinal plane, the passively provided measurements, such as tracking of the beam phase, were used to provide effective transverse feedback for the large beam phase changes during the energy ramp at that time. With this information the phase of the active transverse feedback was adjusted dynamically accordingly to compensate for this change of beam phase. Nevertheless the design and implementation of a longitudinal kicker enabled a better use to be made of the feedback system. A cavity with the central frequency of 1.275 GHz was manufactured and installed into the storage ring.

METHOD

To investigate beam stability and possible effects of the feedback system during injection the normal injection optics are used, but the injection itself is stopped and the beam starts to decay. In addition to a streak camera, the diagnostic capabilities of the feedback system were used to study the bunch length and beam oscillation. In this paper we will look at beam spectra and eigenmodes of the oscillation. For this, the motion of every bunch was recorded on every 12th revolution, using the down-sampling possibility of the feedback system. This results in an extended acquisition window of roughly 200 ms, providing a higher resolution in the relevant frequency range up to 130 kHz. To quantify the improvement on the injection efficiency the beam lifetime or the beam decay rate was measured using a standard DCCT.

INJECTION STABILITY

The first thing to look at is the situation without active feedback. General experience and previous measurements have already shown strong vertical instabilities present during injection. Also current dependent instability regions have been shown [3].

Without Active Feedback

Streak camera measurements, as shown in Figure 1, visualize the situation during injection. The beam centroid can be seen, but strong dipole oscillations with different phases for different bunches smears out the beam motion and make it impossible to measure a clear synchrotron oscillation. But the turning point of the oscillation is visible.

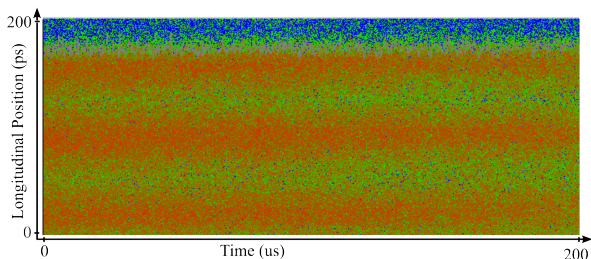


Figure 1: Streak camera recording of the beam at injection energy. Longitudinal feedback is off. The beam centroid in the middle is visible as well as strong synchrotron oscillations. Since the bunches oscillate with different phases the oscillation itself is smeared out, but the turning points are visible.

Analyzing the averaged eigenmodes with the feedback system show multiple prominent modes as seen in Figure 2. The increasing amplitude of these coupled-bunch modes with beam current limit the overall achievable current. These growth rates can be influenced by temperature changes in the four cavities and thus indicate higher order cavity mode eigenfrequencies.

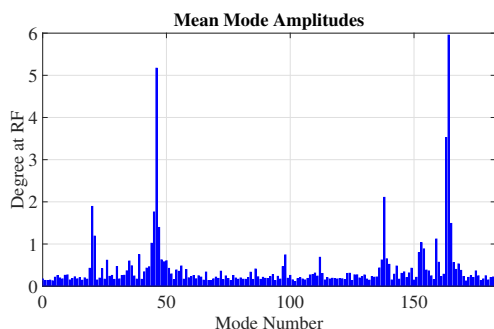


Figure 2: Measured eigenmodes of the longitudinal motion at injection energy without longitudinal feedback. These modes get too strong with increasing beam current preventing further injection.

Active Feedback

Using the longitudinal kicker cavity we are able to significantly decrease the amplitude of the synchrotron motion and stabilize the beam longitudinally during injection increasing the achievable current limit. Figure 3 shows that all except low frequency modes are successfully damped. Also streak camera measurements now show the absence of residual synchrotron oscillation shown in Figure 4. On the one hand this demonstrates clearly the effectiveness of the new longitudinal feedback system during injection. On the other hand we also see a - not unexpected - significant decrease in beam lifetime due to an increase in Touschek scattering. Although the problems caused by longitudinal instabilities are no longer present, the overall injection efficiency drops for higher beam currents to a level where the injection rate equals the decay rate leading to a saturation of the injection

efficiency and therefore also preventing the further injection to higher beam currents.

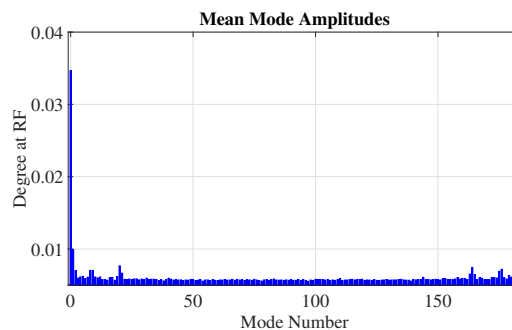


Figure 3: Measured eigenmodes of longitudinal beam motion with active feedback. All modes are successfully damped compared to the situation without feedback as seen in figure 2.

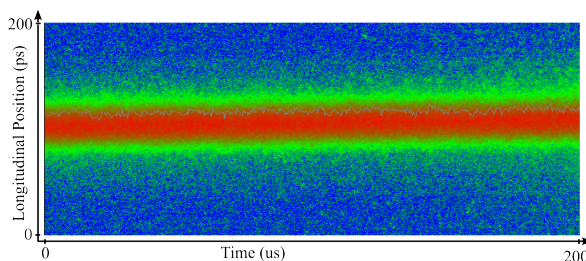


Figure 4: Streak camera recording of beam at injection energy with active longitudinal feedback. The synchrotron oscillation is damped down and only the beam centroid is visible.

DRIVEN EXCITATION

A method to solve limits imposed by decreased Touschek lifetime was found by using the built-in drive capabilities of the feedback system.

Feedback Drive Engine

This drive output can be used on top of the active feedback to excite the beam. Several parameters can be set, to generate an excitation in the range from DC to 250 MHz. Additionally a sweep around the excitation frequency f_e can be set up by a relative frequency range f_r and a period t_p defining the span and speed of the frequency sweep. Furthermore one can also define which bunches shall be driven. This excitation can be changed dynamically if needed, allowing automated adjustments such as switching the excitation on and off based on beam conditions or adjusting for different synchrotron frequencies.

Driving the Beam

The general idea of using an external excitation is to compensate for the decrease in lifetime at the same time as still keeping the instabilities under control. For this we are driving the beam at twice the synchrotron frequency to excite

quadrupole oscillations which lead to bunch lengthening and increase in Touschek lifetime. Currently, the synchrotron frequency during injection is around $f_s = 36.1$ kHz. First tests already have shown that while hitting the beam exactly with $2 \cdot f_s$ is important to achieve the desired effect, the requirement to know the synchrotron frequency exactly can be relaxed due to the sweeping capabilities of the drive engine. One working set of parameters we can use is, for example, a frequency span $f_r = 0.4$ kHz and an excitation frequency $f_e = 72.2$ kHz. The result of this excitation can be measured with the streak camera. Figure 5 shows the excited quadrupole oscillation. The projected amplitude of the oscillation is similar to the situation without active feedback as was shown in Figure 1 leading to a similar Touschek lifetime. But the modes seen in Figure 2 are all suppressed.

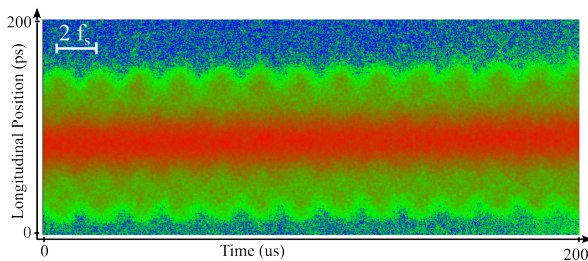


Figure 5: Streak camera recording of longitudinal beam motion with active feedback and driven excitation with $2 \cdot f_s$. The period length of the overlaying oscillation corresponds to the excitation frequency f_e . This quadrupole motion lengthens the beam size and increases Touschek lifetime considerably thus enabling injection to higher beam currents.

The driven excitation can also be observed on the beam spectrum as seen in Figure 6. The excitation frequency f_e as well as the period length t_p can be identified. This also increases the magnitude of the synchrotron peak in the spectrum which can be used to optimise the excitation. For example, in the above mentioned case, reducing the sweep range to 0 cancels the effect on the synchrotron frequency showing that driving the beam with exactly 72.2 kHz would not be precise enough to excite the $2 \cdot f_s$ motion.

Effect on Lifetime

The decrease in lifetime at injection energy with active feedback can be compensated for by using such an excitation. For low to medium beam currents we even managed to improve the lifetime slightly compared to the situation without active feedback. Since evaluating the effect on beam lifetime without active feedback for higher currents is not possible without losing the beam, only the comparison with and without excitation can be studied. With decreasing amplitude of the driven excitation the lifetime decreases to a level where our current average injection rate can only compensate the losses, reducing our injection efficiency close to zero. On the other hand we were able to increase the lifetime by optimising the excitation frequency f_e and the sweep parameters.

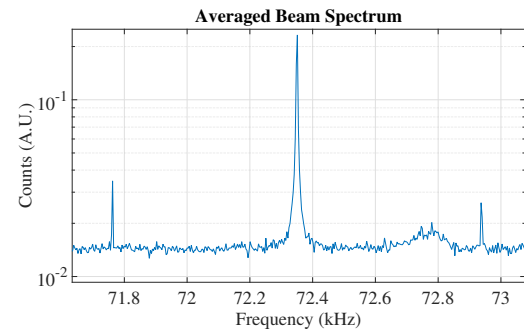


Figure 6: Averaged beam spectrum across the motion of all bunches showing an example for a driven excitation. In this case the excitation frequency is $f_e = 72.35$ kHz represented by the large peak whereas the sidebands correspond to the sweep period.

SUMMARY AND OUTLOOK

With the addition of the longitudinal kicker cavity the last remaining piece of the full active 3D feedback system is now complete. Commissioning was successful and effectiveness of the active feedback has been shown at injection energy, circumventing current limitations due to longitudinal instabilities. An easy to use method was found to counteract a decrease in injection efficiency by using the built-in external drive capabilities of the feedback system. We are in the process of optimising the excitation method. Stable beam at injection energy also opens up the possibility of further systematic studies regarding beam lifetime and injection efficiency - for example, in the tune space or regarding the dynamic aperture. Also experiments are planned to explore exciting the beam in our low α_c mode at 1.3 GeV for possible special applications.

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