OBSERVATION OF BUNCH DEFORMATION AT THE ANKA STORAGE RING*

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Abstract

A dedicated optics with a low momentum compaction factor is used at the ANKA storage ring to reduce the bunch length to generate coherent synchrotron radiation (CSR). A double sweep streak camera is employed to determine the bunch length and shape for different optics and as a function of the beam current. Measurements of the longitudinal bunch profile have been performed for many different momentum compaction factors and various bunch currents. This paper describes the set up of the streak camera experiments and compares the measured bunch lengths to theoretical expectations.

INTRODUCTION

To achieve a continuous reduction of the bunch length by a factor of more than 10 in comparison to the standard user operation, a dedicated optics with a low momentum compaction factor is used at the ANKA storage ring. A short overview of the parameters of the ANKA storage ring can be found in Table 1. The bunch length reduction is achieved by changing the settings of the quadrupole and sextupole magnets mostly, as to decrease the momentum compaction factor α_c [1]. The continuous reduction can be achieved by setting the magnet currents to intermediate values and is referred to as “squeezing”. In April 2009 a new electron source was installed which allows the injection of single bunches; previously only bunch trains could be injected. This has opened up opportunities to systematically study effects of bunch-lengthening and deformation with a streak camera.

Table 1: ANKA Machine Parameters

Parameter	**Normal operation / Low α_c**
Circumference	110.4 m
f_{rev}	2.715 MHz
f_{RF}	499.69 MHz
Harmonic number	184
σ_z (RMS)	45 ps / down to 1 ps
Filling pattern	100 bunches (3 trains) / any

EXPERIMENTAL SETUP

At the ANKA storage ring there is currently one infrared beamline in operation (IR1) at which also the optical range of the spectrum can be used. A second infrared beamline (IR2) is in the commissioning phase and some measurements were done there as well. Both infrared beamlines receive edge radiation from the fringe field of a bending magnet [2]. To avoid dispersive effects as much as possible the focusing of the synchrotron radiation beam was achieved by mirrors only. The radiation exiting the beam port was focussed onto the camera opening with an off-axis parabolic mirror at the IR1 beamline (for measurements at the IR2 a similar setup was used). The measurements were performed with a Hamamatsu C5680 streak camera, which is extended with a synchroscan plugin and a dual time base extender (double sweep unit). With this setup it is possible to separate the signals from bunches in odd RF buckets from the ones in even RF buckets on the screen. We recorded sequences of 500 consecutive dual-scan images in the time range 1 (vertical scale: 190 ps / 512 pixels) and blanking amplitudes (horizontal slow scale) between 500 μs and 2 ms for the full 640 pixels. For these sequences a background subtraction was performed. The phase of the trigger delay unit was locked with a built-in thermal stabilisation feedback from the camera.

Image Analysis

Figure 1 shows a single streak camera image. In order to obtain a bunch profile a projection onto the y-axis needs to be performed. It is clear from this image that the

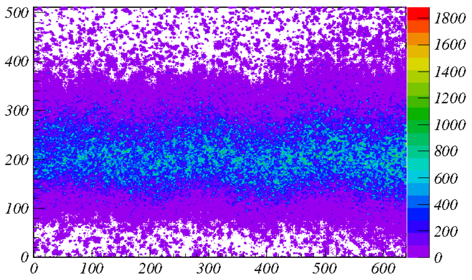

Figure 1: Single streak camera image of a sequence of 500 consecutive images. Vertical scale: 512 pixel = 190 ps; horizontal scale: 640 pixel = 100 μs; recorded in dual-sweep mode. The synchrotron frequency for this measurement was 30.8 kHz which corresponds to a period length of roughly 33 μs.

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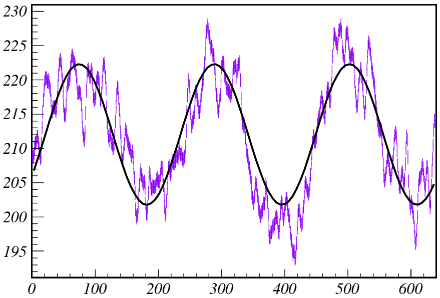

Figure 2: The average of the position of the centre of mass of every vertical slice from Figure 1, whereas the centre of mass was calculated by looking at the 2 slices to the left and the 2 to the right as well. A sinus was fitted to the data and its frequency matches the measured synchrotron frequency of 30.8 kHz nicely.

bunches undergo dipole longitudinal (synchrotron) oscillations which would smear out the projected bunch profile resulting in longer measured bunch lengths. Figure 2 shows the motion of the centre of mass for the same image, where the synchrotron oscillation is clearly visible. In order to minimise this effect, we apply a post-processing algorithm to the acquired images that performs the following steps:

- the constant background is deducted for every image separately
- a slice-wise analysis is performed where the image is cut in 1 pixel wide vertical slices
- the centre of mass for each of those slices is deducted from the position values of each pixel in that vertical slice before they are filled into a histogram, thus minimising the effects of the oscillation
- this procedure is performed for every one of the 640 vertical pixel slices in every image and every one of the 500 images to obtain enough statistics

⇒ the result is a smooth bunch profile

Systematic Studies

In order to acquire a deeper understanding of the streak camera's characteristics and of the analysis routine systematic studies were needed.

To understand the resolution limits of the streak camera and the influence of the jitter on the trigger signal, test measurements with a 50-fs-laser ($\lambda = 800nm$) synchronised to the 500 MHz RF frequency were performed.The FWHM of the laser pulse was found to be 11 pixels which equals 4.1 ps. This value was quadratically subtracted from the measured bunch length values. The profiles have not been corrected for this broadening and the exact effects on the asymmetry which might play a role for the measurements with very short pulses will have to be studied in greater detail.

The input slit opening was varied between 20 and 40 μm without any noticeable profile widening (neither for laser nor for synchrotron light).

The blanking amplitude (length of the slow sweep) was varied between 100 μs and 2 ms and the bunch length was extracted both from the oscillation-corrected profile and from the raw-profile where only the background was deducted. Whereas there was no significant change in the width of the raw-profiles, the effectiveness of the oscillation-correction increased slightly for shorter blanking amplitudes at which only a few period lengths of the synchrotron oscillation fit on the screen.

For a set with rather long pulse lengths (15 ps rms) there was no visible effect of a dispersive pulse broadening when the band pass filter (central wavelength 650 nm; spectral width 40 nm) was removed, for shorter bunch lengths all measurements were only performed with the filter. We estimate the effects of dispersion as rather small because apart from the two windows and the achromatic input lens of the streak camera no dispersive optics are in use.

To study if a low light intensity has any effects on the measured bunch profiles, the beam was attenuated with neutral density filters. The normalised profiles with either the 0.1 (10% transmission) or the 0.2 (20% transmission) filter in the beam path look identical, but the one recorded with both ND filters (2% transmission) placed in the beam path shows a slight shortening of 0.8 ps (4% of the pulse length). Further measurements with a continuous reduction of beam intensity are planned to characterise this effect fully. For now bunch length values for currents which are lower than 0.2 mA have been excluded from the results.

Possible influences on the oscillation-correction when the centre of mass of a slice was calculated only for the pixels in that slice or also for the neighbouring pixels (investigations were made for 1 and 2 neighbouring pixels to both sides of the slice) were investigated. Here only a very slight variation could be observed that is absorbed in the measurement uncertainties.

RESULTS

The longitudinal electron distribution in the phase space is described by the Fokker-Planck equation. Its stationary solution is called Haissinski equation and depends on the existing wake fields and therefore on the impedance of the storage ring. The real part of the impedance is known to cause energy loss. This leads to asymmetric bunch shapes which lean forward to compensate the energy decrease in the RF cavities. The streak camera measurements depicted in Figures 3 and 4 show this increasing asymmetry in the bunch shape and a bunch lengthening for increasing currents in the low alpha optics. It is also clearly visible that the deformation over the same current range is stronger for shorter bunches. Whereas for long bunches as in the normal user operation at 2.5 GeV the bunch profiles show a perfectly Gaussian shape that does not change within the observed current range (not depicted). The evaluated bunch shapes can help to determine the impedance of the storage ring for these optics. A first comparison of the measured shapes and expected distributions for two different impedances has been made [3], but further investigations will be needed.

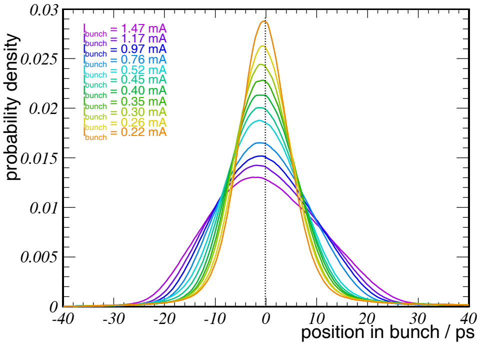

Figure 3: Normalised bunch profiles for different bunch currents at a synchrotron tune of 5.6 kHz, recorded with the streak camera.The RMS bunch lengths for those currents range from 4.5 (at 0.22 mA) to 11.9 ps (at 1.47 mA).

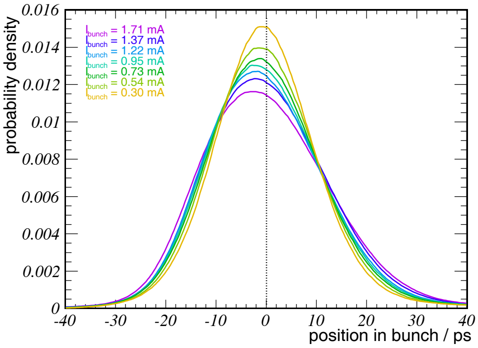

Figure 4: Normalised bunch profiles for different bunch currents at a synchrotron tune of 15.1 kHz, recorded with the streak camera. The RMS bunch lengths for those currents range from 9.5 (at 0.3 mA) to 12.8 ps (at 1.71 mA).

The bunch lengths have been extracted from the bunch profiles by determining the FWHM, then the resolution/jitter contribution of 4.1 ps was quadratically subtracted and a RMS-equivalent value for a Gaussian profile calculated.

In Figure 5 the bunch lengths for various squeeze states are shown in dependence of bunch current. It is expected that they converge towards a constant "zero current bunch length" for low bunch currents; for bunch currents above the Stupakov threshold a turbulent bunch lengthening behaviour $\propto I_{bunch}^{3/7}$ is expected [4]; where this dependence has previously been verified for the ANKA storage ring [5]. Similar to the fits performed in [6] fits were done assuming potential well deformation to cause the bunch lengthening with the constraints that they converge towards the zero current bunch length σ_0 for very low bunch currents and that they exhibit a $\propto I_{bunch}^{3/7}$ behaviour for high bunch currents:

$$\sigma_z^4 = \sigma_0^4 + \left(\frac{I}{\xi_0}\right)^{12/7} \tag{1}$$

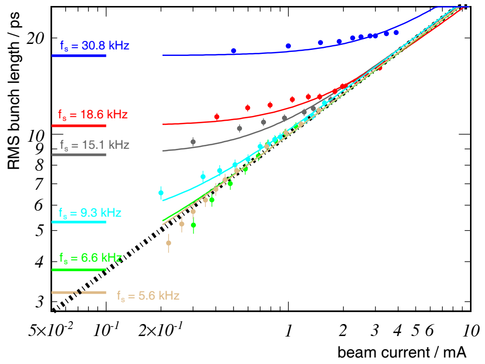

Figure 5: The bunch length as a function of bunch current for different squeeze states is visualised. A static uncertainty of ± 2 pixels on the FWHM of the bunch profiles from which the bunch length data is extracted has been assumed. The dotted lines to the left show the predicted zero current bunch length. The dotted black line marks the Stupakov threshold $\propto I_{bunch}^{3/7}$ [4].

Here σ_0 was calculated from the synchrotron tune and ξ_0 is a fit parameter. The values for a synchrotron frequency of 9 kHz and higher show the expected behaviour, whereas for the two sets with the lowest synchrotron frequencies the bunch lengths seem to drop below the threshold for low currents. It is unlikely that solely systematic effects cause this behaviour but further investigations for intermediate values will have to be undertaken.

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