Bunch Length Measurements in the SLC Damping Ring

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Abstract

The synchrotron light of the SLC damping ring was used to measure the bunch length with a streak camera at different times in the damping cycle. There are bunch length oscillations after injection, different equilibrium length during the cycle due to rf manipulations to avoid microwave instability oscillations, and just before extraction there is a longitudinal phase space rotation (bunch muncher) to shorten the bunch length. Measurements under these different conditions are presented and compared with BPM pulse height signals. Calibration and adjustment issues and the connection of the streak camera to the SLC control system are also discussed.

1 Introduction

Different techniques exist to measure the bunch length of $\sigma_z = 2$ to 25 mm. A bunch length measurement in the damping ring (DR) using the synchrotron light and a streak camera has the advantage that it is a non-invasive measurement and can be used at different times in the damping cycle. In contrast, a bunch length measurement with a screen in the dispersive region of the ring-to-linac (RTL) compression region is invasive (a wire might be suitable), measures only the extracted bunch length, and is limited by the non-linear RF slope for longer bunch length. We will discuss here the first technique. After describing the set up and calibration, we will present measurements during the store time and discuss their implications for longitudinal phase space.

2 Streak Camera Set Up

The synchrotron light for the DRs is guided with five mirrors and two achromatic lenses over 15 m to an optical table, where it is split for turn by turn size measurements with a gated camera [1] and for length measurements with a streak camera. The streak camera is manufactured by Hadland Photonics [2] with a IMACON 500 streak tube.

2.1 Resolution

The advertised resolution is 2 ps. The measured resolution is 6 ps (FWHM) [3] determind using a femto-second laser pulse. This corresponds to a σ-resolution of 0.8 mm and is sufficient for most of the measured bunch lengths between 2 and 25 mm (σ_z). The thickness of the cumulated lenses and windows of about 50 mm must also be taken into account. With no frequency filter a delta pulse with a wide spectrum of 400 to 800 nm produces about a 7 ps FWHM long signal. Achromats compensate this effect only slightly (actually they overcompensate), since they are in general not compensated to be isochronous.

2.2 Connection to SLC Control System

Since the normal one-dimensional analyser of the streak camera could be used only locally, the output of the streak camera was imaged to a gated camera (spare) which has a high gain so that even single photons are detected. With this set up we could see correlations between y and z at injection (or x and z) and use digitization techniques for a normal camera, which is supported by the SLC control system. These include calibration of the scales, projections in z (and y) and fitting with a gaussian (or other) distribution to the data, statistical averaging, correlation plots with other parameters (e.g. store time), etc.

2.3 Calibration

The inclusion of the gated camera made a calibration necessary. For slow sweep speeds the shift of the centroid in mm could be compared with the change in time (0.1 ns steps) of the variable delay unit (VDU). A correct calibration will give a slope of $A = 300$ mm/ns the velocity of light.

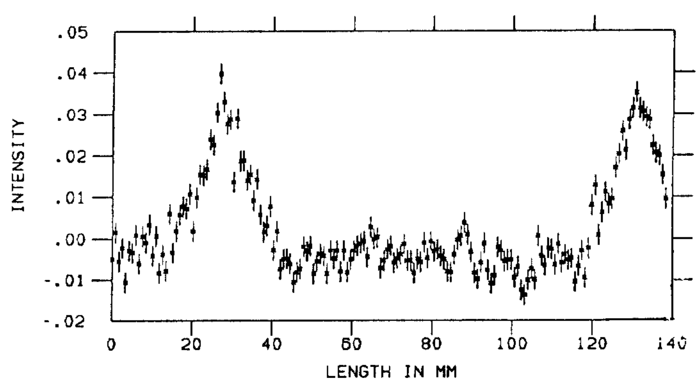

Figure 1: Calibration technique.

For the faster sweep speeds the light was splitted, delayed (105 mm) and combined. The double pulse (bottom) shows exactly this separation after the right calibration.

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For faster sweep speeds this technique is not appropriate, since the timing jitter of 20 ps dominates the measurement. Therefore the light was split and combined after 105 ± 5 mm. The separation of this double pulse (Fig. 1). was measured with the streak camera and the calibration adjusted accordingly (15 % off from expected scaled value). Tab. 1 summarizes the measured values.

Streak Camera Calibration			
Streak speed	Digitizer bin/mm(m)	Comparison ps/ch (old)	Resolution in mm
5 ns/mm	11.4	80.9	270
2 ns/mm	37.9	33.5	107
1 ns/mm	67.7	18.1	59
500 ps/mm	130.0	8.65	42
200 ps/mm	270.0	3.49	22
100 ps/mm	0.57	1.73	14
50 ps/mm	1.14	0.89	6.5
20 ps/mm	4.1(3.6)	0.31	≈2

Table 1: Calibration summary.

For each streak speed setting the video digitizer was calibrated. The inverse of the old calibration (in ps/channel) should correspond to the new one (exception: 20 ps/mm). The resolution is mainly limited by the slit opening and spatial camera resolution for the slow speeds and the streak tube itself (timing of electrons) for the fast speeds.

3 Bunch Length Measurements

Different times during the store cycle were studied corresponding to the different type of investigation. The first turn, injection oscillation, longer bunch length during the low rf voltage ("DR-ramp") and the pre-compression at the end of store time ("bunch muncher") were all studied.

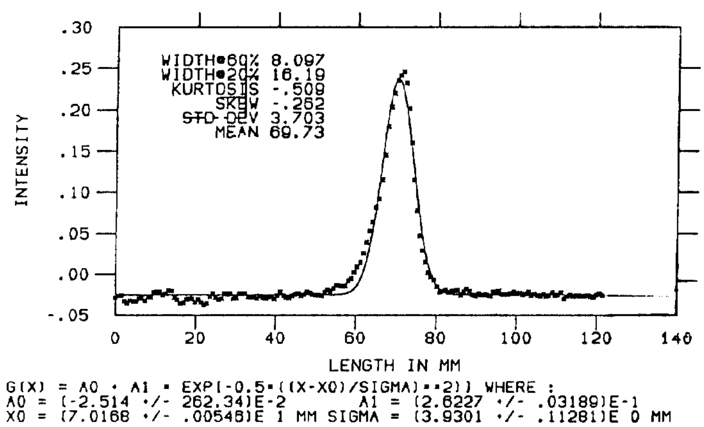

Figure 2: Bunch distribution after the first turn.

The bunch length is determined not only by the injected length but also by the length energy correlation, which was in this case pretty high causing a long bunch with a big asymmetry.

3.1 First Turn

After nearly one turn the first measurement can be done. Sizes of 2-4 mm (σ_z) were observed, correlations with y seen and asymmetries recognized (Fig. 2). Even pre- or postbunches, one S-band bucket away from the main bunch (λ = 105 mm) of up to 5 % were observed. This information was used to optimize injection parameters.

3.2 Injection Oscillations

Since the bunch length and the energy spread of the injected bunch is not matched to the longitudinal acceptance of the DR (this could be done with a "bunch muncher", see below), the beam performs bunch length oscillations with an amplitude of ±13 mm around the equilibrium of 15 mm (σ_z). (Fig. 3). These decohere after about 0.3 ms or 2500 turns which seems long, but one has to consider that a partly filamented beam with for instance three peaks in the projected distribution (observed) will be fitted with only one Gaussian with a too small σ_z. The initial big value is mainly the resolution of the 2nd fastest sweep speed of the streak camera used for these mainly big sizes.

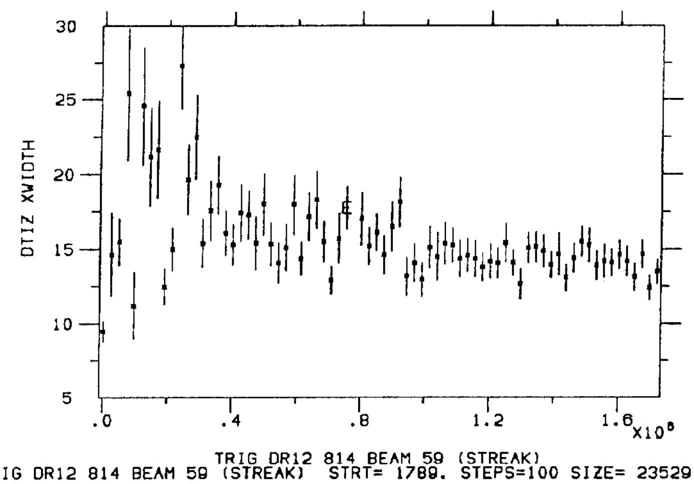

Figure 3: Injection oscillations of the bunch length.

The digitized bunch length (XWIDTH) in mm is plotted versus the time in 200 turn steps (23529.4 ns) directly after injection. The measured size includes the resolution (6.5 mm) which must be subtracted in quadrature.

3.3 DR RF Voltage Variation

After the injected beam is captured at high rf voltage (V_{rf} = 800 kV) the voltage is reduced to about 400 kV to achieve a longer bunch length which is insensitive to microwave instability oscillations [4]. The bunch length (resolution subtracted) changes from 11.0 to 17.0 and back to 10.5 mm (Fig. 4). It should be mentioned that the longitudinal phase space is not totally damped down at the extraction time and that the bunch length is much longer than the design value of 5 mm. The higher energy spread which turns into bunch length in the linac (with no bunch muncher) induced a bunch length variation which could not be detected directly.

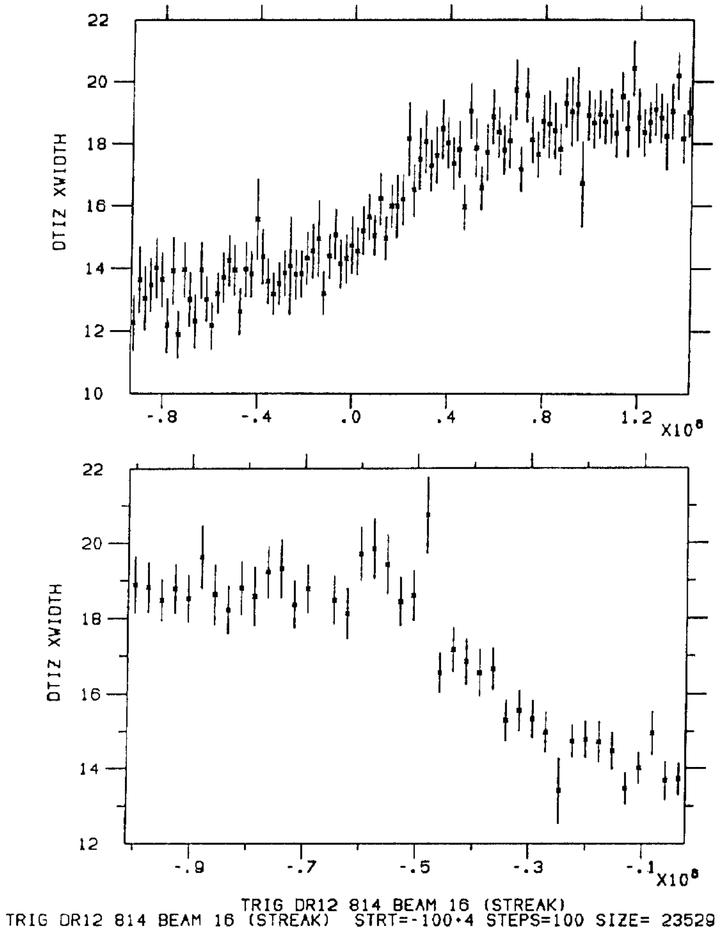

Figure 4: Bunch length during the DR RF ramp.

After about 2.5 ms (zero here) after injection the rf voltage in the damping ring is reduced by a factor of roughly two (top). Then about 5 ms later or 0.6 ms before extraction (bottom) the rf voltage is set to its nominal value and the bunch length starts to decrease but not totally to its equilibrium.

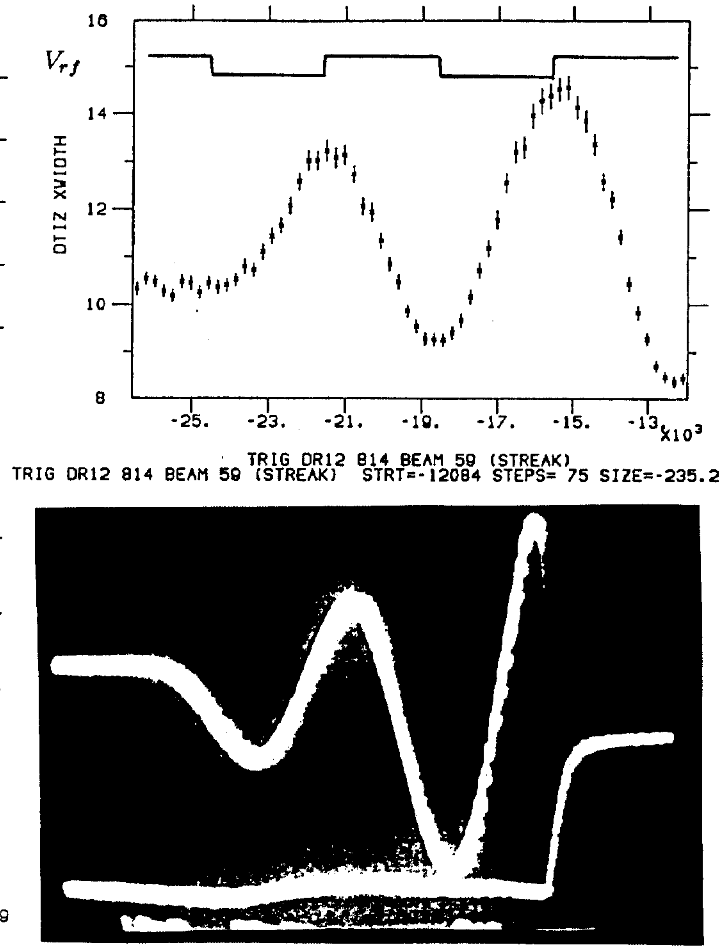

Figure 5: Pre-compression of the bunch length.

The measured (digitized) bunch length in mm is plotted against the last 15 μs before extraction. The pre-compression was set to 20 % =(10.5-8.4)/10.5 (top). The inverse of the peak signal of a BPM ("sum-signal") shows a similar response (middle) while the phase (bottom) is mainly compensated.

3.4 Pre-Compression (Bunch Muncher)

To reduce the extracted bunch length at the end of the store time, two 2.5 μs long dips in the rf-amplitude are applied. This excites a bunch rotation in longitudinal phase space [5]. A pre-compressed bunch length for injection into the RTL is achieved (Fig. 5).

4 Conclusion

After calibration the bunch length measurements with the streak camera give absolute values. Beyond the easier to use BPM peak signal, which could be also calibrated e.g. with the streak camera, the streak camera gives additional information about the asymmetry, the y-z (x-z) correlations and pre- or post-bunches.

Acknowledgement

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References

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