Bunch Length Measurements at the BESSY Storage Ring

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Abstract

At the BESSY e^- storage ring the zero current bunch length can be varied over a wide range from $\sigma_{l_0} = 0.7cm$ to $\sigma_{l_0} = 8cm$ by changing the rf voltage and using either the 500 MHz or the 62.4 MHz rf system. That means, measurement can be done below and above cutoff frequency of the beam pipe with radius r= 4 cm. Bunch length, energy spread, the synchrotron sidebands and the shift of the synchronous phase are measured for different rf settings with bunch currents ranging from 0.1 to 100 mA. For long bunches energy spread and bunch lengthening can be explained by potential well distortion and microwave instability. Bunches shorter than 2 cm show additional bunch lengthening and increase of energy spread. In all cases coupling of synchrotron sidebands is observed.

1 BEAM INSTRUMENTATION

Fig.1 show the experimental setup for the measurements. The measured data are taken only in single bunch operation, to avoid multibunch instabilities.

The longitudinal current distribution in the bunch is measured by looking at the time dependent intensity profile of the synchrotron radiation from a bending magnet. The light pulse is analysed by two different bunch length monitors:

A streak camera with a time resolution of a few picoseconds triggered by a revolution synchronous signal from the master generator of the rf-systems is used over the whole bunch length range.

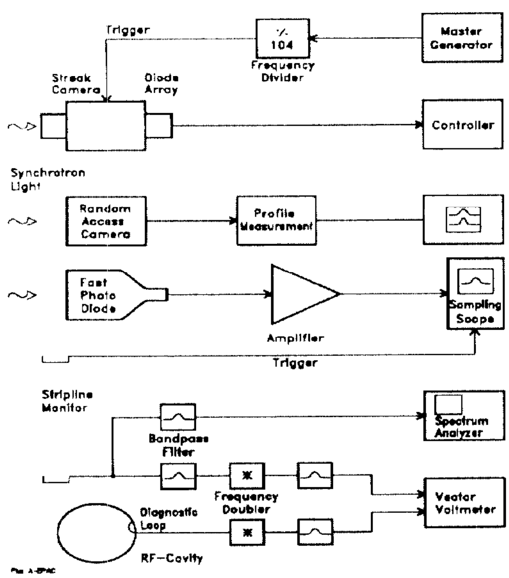

Figure 1: experimental setup

Alternatively a photo diode with a risetime of 70 psec can be used. The amplified signal is analyzed with a sampling scope. To get rid of the rf noise and the coherent dipole motion of the bunch, the scope is triggered by the bunch signal from a stripline monitor. The risetime of the total system is measured to about 105 psec. This system is used only for measuring long bunches.

The energy spread is derived from the horizontal beam size from an optical beam profile monitor (random access camera, RAC) at a position with high dispersion. The horizontal beam size σ_x is given by the hor. emitance ϵ_x, the hor. beta function β_x, the dispersion D at the place of the camera and the energy spread σ_E by:

$$\sigma_x = \sqrt{\epsilon_x \beta_x + D^2 \sigma_E^2} \tag{1}$$

A spectrum analyzer is used to record the spontanous synchrotron sideband spectrum from the signal of a stripline monitor after passing a bandpass filter. The measurement is done at a higher harmonic of the rf frequency. No external exitation of the beam was necessary to observe the synchrotron sideband spectrum.

The loss factor k of the vacuum camber is determined directly, by measureing the phase shift of the synchronous phase using a vector voltmeter. A broadband resonator with frequency f_r=5.1 GHz, quality factor of Q=0.23 and an impedance of $\mid \frac{Z}{n} \mid = 2.2\Omega$ gives a good fit to the data.

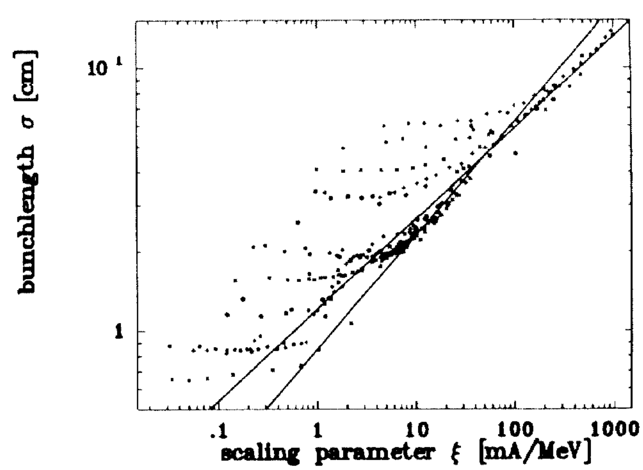

Figure 2: bunch length versus scaling parameter ξ

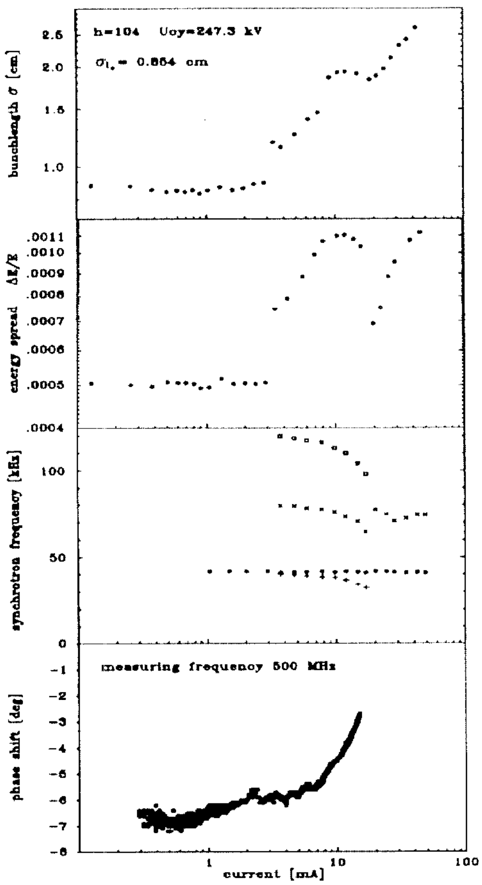

Figure 3: bunch length, energy spread, synchrotron sidebands and phaseshift of the synchronous phase versus current for $\sigma_{l_0} = 0.85cm$

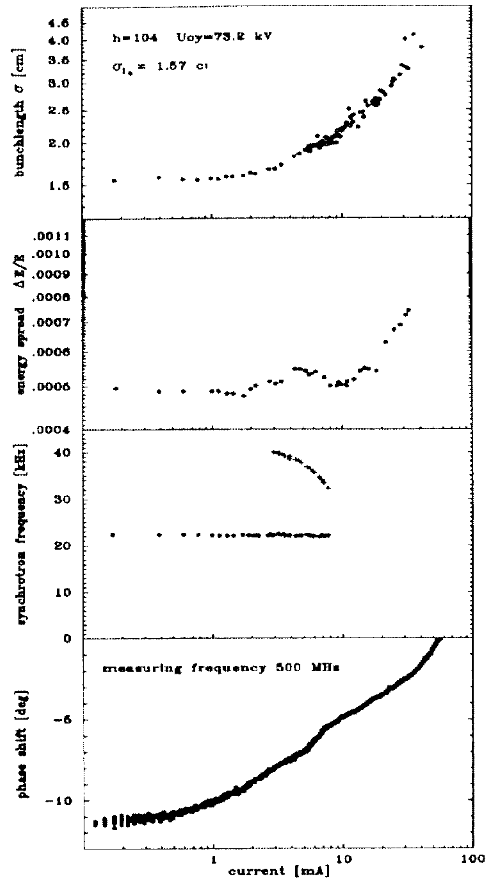

Figure 4: bunch length, energy spread, synchrotron sidebands and phaseshift of the synchronous phase versus current for $\sigma_{l_0} = 1.6cm$

A detailed description of this setup and the data will be presented in [1].

2 EXPERIMENTAL RESULTS

At very low currents the bunch length is equal to the natural bunch length σ_{l_0}. Above a certain current, bunch length and energy width increase due to the microwave instability. This range can be analyzed by comparing the measured data to the model developed at SPEAR [2]. The scaling parameter ξ is defined as $\xi = \frac{I\alpha}{\nu_s^2 E}$ where I is the average bunch current, α the momentum compaction factor, ν_s the synchrotron tune and E the beam energy. According to this model, the bunch length σ_l depends on the parameter ξ as

$$\sigma_l \propto (\xi Z_0 R^3)^{\frac{1}{2+a}} \tag{2}$$

$$Z(\omega) = 2\pi R Z_0 \omega^a \tag{3}$$

R is the average ring radius and Z_0 the longitudinal impedance responsible for the instability. When plotting all bunch length data versus ξ in Fig.2, the frequency dependent factor can be determined: a= +0.3 for bunches from 2 cm to 5 cm and a= + 0.9 for bunches longer than 5 cm. This is close to the theoretical value of a= +1 for very long bunches. The range of bunches shorter than 2 cm show a different behavior and can not be explained by this model.

In Fig.3,4,5,7 the bunch length, energy spread, synchrotron sidebands and the phase shift of the synchronous phase is plotted versus current for different rf settings and zero current bunch length of σ_{l_0}= 0.85 ... 6.1 cm.

The energy spread for long bunches show clearly the threshold for microwave instability. The Keil Schnell criterion [3] applied to bunched beam [4] gives:

$$I_{th} = \frac{\sqrt{2\pi}\alpha^2 (E/e)}{\nu_s \mid \frac{Z}{n} \mid} (\frac{\sigma_E}{E})^3 \tag{4}$$

where α is the momentum compaction factor. From the threshold current I_{th} we get the value of the impedance driving the microwave instability to $\mid \frac{Z}{n} \mid \approx 1.5\Omega$. For bunches shorter than 2 cm a strong extra widening is seen in the energy spread and in the bunch length, so that this theory doesn't fit.

There is an additional bunch lengthening at all bunch length over the whole current range. This can be interpreted by the potential well distortion theory [5]. From

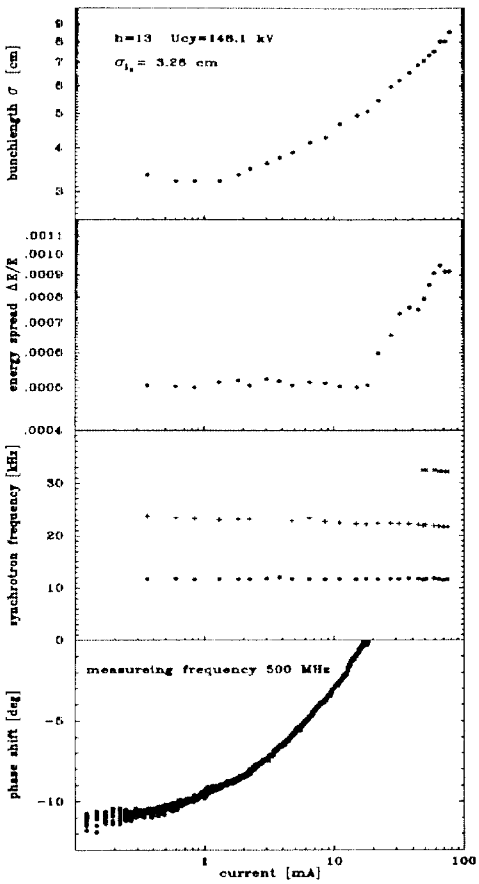

Figure 5: bunch length, energy spread, synchrotron sidebands and phaseshift of the synchronous phase versus current for $\sigma_{l_0} = 3.3cm$

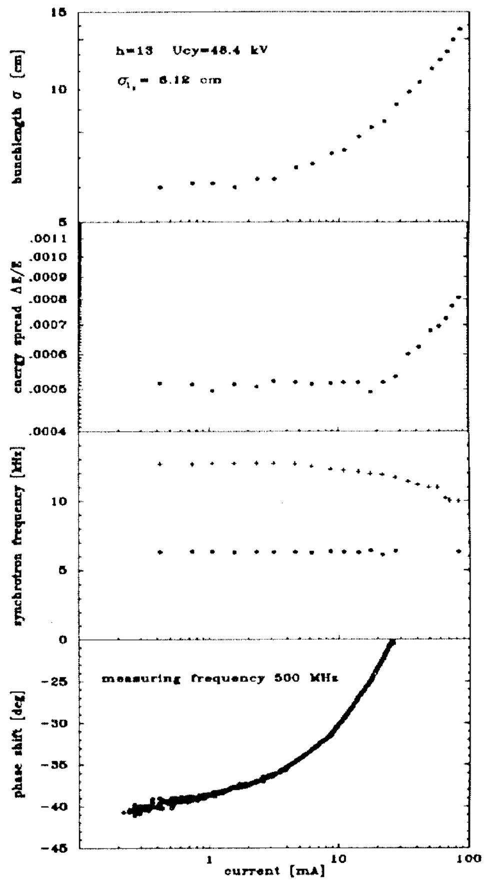

Figure 7: bunch length, energy spread, synchrotron sidebands and phaseshift of the synchronous phase versus current for $\sigma_{l_0} = 6.1cm$

bunch lengthening for currents below threshold, the effective impedance driving the potential well distortion can be determined to be $|\frac{Z}{n}|_{eff} \approx 4\Omega$ for long bunches. Potential well distortion will cause a shift of the coherent synchrotron sidebands except the dipole mode [6]. Frequency shifts are seen well, but the shifts are too small to cause all the bunch lengthening.

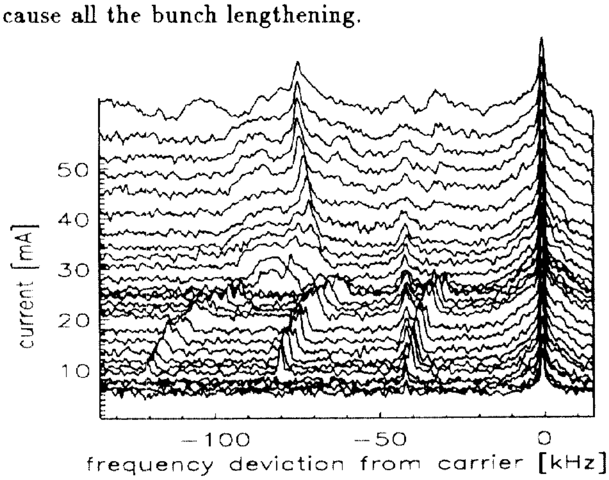

Figure 6: synchrotron sidebands for $\sigma_{l_0} = 0.85cm$

In the synchrotron sidebands a coupling of modes is observed. Fig.6 shows the spectrum versus current for short bunches with $\sigma_{l_0} = 0.85cm$. The coherent dipole mode doesn't shift. A second mode is splitting out of the dipole mode. Its frequency would fit to the frequency of an incoherent synchrotron frequency. The quadrupole mode and sextupole mode are also shifting. At a current of 19 mA both modes disappear and a coupled mode grows up. This is exactly the current, when the extra energy widening discussed above disappears. At longer bunches a coupling of higher modes is observed, but it has no influence on the energy width and the bunch length.

3 REFERENCES

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